An Outline of the Available and Necessary Information for the Sugar River/Badger Mill Creek Study

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Introduction

The Verona Urban Service Area (USA) has a development area of 3,849 acres (developed and developable acreage). The *Dane County Water Quality Plan* allows a maximum 2030 development area of 5,849 for the USA. Therefore, 2,000 additional developable acres can be added to the USA (the forecast will be next updated based on 2010 Census data for year 2040).

The Verona USA has expanded by 804 developable acres since year 2000. An additional 249 acres have been added to the USA as environmental corridors (areas that are inside the USA but are protected from development). Most of this expansion has occurred in the Badger Mill Creek watershed, adding to the 48% of the watershed area which is already urbanized or committed to urban development. Because the City of Verona is growing toward the Sugar River, a sensitive cold water fishery and Exceptional Resource Water, the most recent Verona USA amendment included a recommendation for the City to *"initiate a comprehensive long-range planning process for the future long-term growth of the City of Verona. The plan should aim to protect the sensitive resources of the Sugar River."*

In response to this recommendation the City of Verona adopted a resolution in June 2005, "supporting natural resources planning in portions of the Badger Mill Creek/Sugar River watershed" (see Appendix 5). The resolution identified a study area (1,700 acres; see Map 1) in which "prior to permitting development... the City of Verona will conduct a planning process designed to determine locations where development can occur in compliance with established federal, state, county and local rules and regulations"; and that "the planning policies and concepts developed through the Badger Mill Creek and Sugar River natural resource planning process will be used to guide the development of the City's environmental protection and land use plans for the planning area".

The present document is the result of consultation with key staff from WDNR (Jim Amrhein and Mike Sorge), WGNHS (Ken Bradbury), USGS (Randy Hunt), and Dane County (Jeremy Balousek and Michelle Richardson) to outline existing information and findings from current research in stream protection, stormwater management, and development impact mitigation, to assist the City of Verona in scoping the elements of the planning process it has resolved to undertake.

Natural Resource Features

Soils and Geology. The study area is located about half a mile from the edge of the Johnstown terminal moraine. The surficial geology of the study area is dominated by three general formations (from "Pleistocene Geology of Dane County, Wisconsin" by Lee Clayton and John Attig; WGNHS, 1997):

- Non-glaciated stream sediment along Badger Mill Creek and the Sugar River and their floodplains. This area is characterized by thick deposits of sand and gravelly sand deposited on floodplains of modern rivers, overlain in places by thin, silty overbank sediment which is overlain by thin and patchy peat.
- Meltwater-stream sediment in a wide (±1,000 feet) band upland from the Sugar River and Badger Mill Creek. This area is characterized by thick deposits of sand and gravel, deposited on the outwash plain by braided streams that carried glacial meltwater during the Wisconsin Glaciation.
- Hillslopes underlain by early paleozoic rock in unglaciated areas, including dolomite on the uplands, and sandstone in the scarps at the edge of the uplands. Rock is overlain by clay or sand, which in turn is overlain by windblown silt.

Task 1: A detailed evaluation of the stratigraphy of the study area is needed to determine the permeability of the shallow bedrock and other soil strata and their water conveyance capacity in feeding the springs and groundwater seeps along the beds and banks of Badger Mill Creek and the Sugar River.

The soils of the study area in three general associations (from "Soil Survey of Dane County, Wisconsin," USDA):

- The Sugar River and its floodplain are dominated by the Otto-Orion-Troxel Association, composed of poorly drained to well drained deep silt loams underlain by silt loam and formed in alluvium.
- The upland areas (see high elevation areas on Map 2) located on both sides of Locust Drive in the west-southwest quarter of the study area, and on both sides of Valley Road in its half-mile stretch west of STH 69. These upland areas are dominated by the Basco-Elkmound-Gale Association, composed of moderately well drained to somewhat excessively drained, thin to moderately deep silt loams and sandy loams underlain by sandstone.
- The rest of the study area is dominated by the Batavia-Houghton-Dresden Association, composed of well drained and poorly drained, deep and moderately deep silt loams and mucks underlain by silt, sand, and gravel formed in outwash material.

The presence of shallow bedrock and silty soils can limit active infiltration measures. Under certain circumstances native soils and substrates can be replaced by engineered soils to maximize infiltration. In excessively permeable soils, it is possible to infiltrate clean rooftop runoff or use engineered soils to augment the capacity of the native soils to attenuate pollutants in the stormwater. Because the study area is near sensitive streams and their associated wetlands, it is necessary that aggressive infiltration practices be implemented in the area.

Task 2: A detailed study of the soils and soil substrates, bedrock type, and soil grain distribution and texture are necessary for a definitive determination of the suitability of sites for active post-development infiltration measures.

Table 1 shows the soils of the study area, and their extent and characteristics (also see Map 3). The source of the information is the Soil Survey of Dane County Wisconsin.

Table 1- Verona Study Area Soils

Soil Unit	AREA (ac.)	Description
Basco Silt Loam; BaB2	101.806	Moderately deep, well drained and moderately well drained, gently sloping to steep soils on side slopes and at the tops of ridges in the high uplands. Poses severe to very severe limitations for development due to erodibility.
Basco Silt Loam; BaC2	123.607	
Basco Silt Loam; BaD2	59.430	
Batavia Silt Loam; BbA	172.147	Deep, well drained soils on high benches formed on loamy outwash. Soils have high fertility and moderate permeability. Poses slight to moderate limitation for development. 150-155 Bu/acre corn yield.
Batavia Silt Loam; BbB	19.365	
Chaseburg Silt Loam; ChB	13.422	Deep, well drained and moderately well drained soils in drainageways, streams, and low sides of steep hills. High fertility, moderate permeability. Poses moderate to severe limitation for development due to flooding. 150 Bu/acre corn yield.
Dresden Silt Loam; DsC2	3.580	Formed in stream valley benches. Moderately deep. Moderate limitation to development. Substratum has rapid permeability. Medium fertility 75 Bu/acre corn yield
Dunbarton Silt Loam; DuB2	15.734	Shallow, well drained soils on uplands. Soils have low fertility and moderately slow permeability. Poses moderate to very severe limitations for development due to shallow depth to bedrock.
Dunbarton Silt Loam; DuC2	10.528	
Elburn Silt Loam; EfB	3.166	Deep, somewhat poorly drained soils underlain by outwash sand and gravel at a depth of 44 to 880 inches. Soils have high fertility and moderately slow permeability in the subsoil. Poses moderate to severe limitation for development due to seasonal high water table. 160 Bu/acre corn yield.
Elburn Silt Loam; gravelly substratum; EgA	152.133	
Elkmound Sandy Loam; EmC2	9.555	Shallow, somewhat excessively drained, sloping to very steep soils on uplands formed in residuum weathered from sandstone bedrock. Moderately rapid permeability, low fertility, and severe to very severe limitation for development due to shallow bedrock. Where the bedrock is cemented, it has low permeability and acts as a confining layer for percolating water.
Elkmound Sandy Loam; EmD2	22.865	
Elkmound Sandy Loam; EmE2	4.953	
Elkmound Sandy Loam; EmF	2.277	

Soil Unit	AREA (ac.)	Description
Gale Silt Loam; GaB	8.698	Moderately deep, well drained, gently sloping to moderately steep soils on uplands, formed in a moderately deep layer of loess. Moderate permeability, medium fertility, and moderate to severe hazard of erosion due to slope. Sandstone bedrock is rapidly permeable. Poses moderate limitation to development. 95-105 Bu/acre corn yield.
Gale Silt Loam; GaC2	8.508	
Hixton Loam; HbB	4.141	Moderately deep, well drained soils on sandstone uplands. Soils have medium fertility, moderate permeability, and pose severe hazard of erosion. Pose moderate limitation to development due to shallow bedrock. Prime agricultural soils with 90 Bu/acre corn yield.
Hixton Loam; HbC2	2.742	
Huntsville Silt Loam; HuB	5.727	Deep, well drained and moderately well drained soils in drainageways and small draws. Soils have high fertility and moderate permeability. Poses severe limitation for development due to flooding. 130 Bu/acre corn yield.
Kegonsa Silt Loam; KeA	138.651	Moderately deep, well drained soils on benches on outwash plains. Soils have medium fertility. Permeability is moderate in the subsoil and rapid in the substratum. Slight to moderate limitation for development. 125 Bu/acre corn yield.
Kegonsa Silt Loam; KeB	49.795	
New Glarus Silt Loam; NeB2	1.366	Moderately deep, well drained soils on uplands. Soils have medium fertility and moderate to moderately slow permeability. Poses moderate to severe limitations for development due to dolomite bedrock at shallow depth. 115 Bu/acre corn yield.
New Glarus Silt Loam; NeC2	64.103	
New Glarus Silt Loam; NeD2	43.647	
Orion Silt Loam; Or	13.564	Formed in flood plains and stream bottoms. Deep, poorly drained soils. Very severe limitation to development due to flooding. High fertility. Prime Ag Soil where protected from flooding. 105 Bu/acre corn yield
Orion Silt Loam, wet; Os	47.110	Formed in low bottom lands of stream valleys. Deep, poorly drained soils. Very severe limitation to development due to high water table & flooding. High fertility. Prime Ag Soil where protected from flooding and high water table. 105 Bu/acre corn yield
Otter Silt Loam; Ot	80.976	Deep, poorly drained, nearly level soils on stream bottoms, formed in silty alluvium. High fertility, moderately slow permeability, and seasonally high water table and flooding. Poses very severe limitation to development due to flooding. 105 Bu/acre corn yield.
Palms Muck; Pa	14.387	Deep, very poorly drained, nearly level organic soils on low benches in stream valleys. Medium fertility, rapid permeability, seasonal high water table and flooding, very severe limitation to development. 115 Bu/acre corn yield.
Plano Silt Loam; PoA	158.710	Deep, well drained soils underlain by sand and gravel outwash at a depth of 44 to 70 inches. Substrate has rapid permeability. Slight to moderate limitations for development. 155 Bu/acre corn yield.

Soil Unit	AREA (ac.)	Description
Plano Silt Loam; PoB	17.753	
Radford Silt Loam; RaA	107.617	Deep, somewhat poorly drained soils in low drainageways and stream channels. Soils have high fertility and moderate permeability. Pose severe to very severe limitation for development due to seasonally high water table and flooding and low bearing capacity. Prime agricultural soils where protected from flooding, 110 Bu/acre corn yield.
Sable Silty Clay Loam; SaA	37.698	Deep, nearly level, poorly drained soils on low benches in stream valleys. Sandy outwash underlies the silt in most places. High fertility, moderate permeability, seasonally high water table, and very severe limitation to development. 130 Bu/acre corn yield.
Seaton Silt Loam; SmB	40.222	Formed on glaciated uplands. Deep, moderately well drained soils. Severe hazard of erosion. Severe limitation to development due to low bearing capacity of soil when wet. High fertility. 90 Bu/acre corn yield
Seaton Silt Loam; SmC2	5.129	
Troxel Silt Loam; TrB	8.800	Deep, well drained to moderately well drained soils formed in drainageways. Subject to seasonal flooding of short duration. Poses severe limitation to development due to flooding. 145 Bu/acre corn yield.
Virgil Silt Loam, gravelly substratum; VwA	72.074	Deep, somewhat poorly drained soils on low benches on uplands and in stream valleys, underlain by sand and gravel outwash. Soils have high fertility and moderately slow permeability. Severe limitations for development due to seasonal high water table. 150 Bu/acre corn yield.
Wacousta Silty Clay Loam; Wa	55.912	Deep, nearly level, poorly drained soils on low benches in old lake basins. Low fertility, moderately slow permeability, and seasonally high water table and flooding. Very severe limitation for development. 105 Bu/acre corn yield.
Total Area	1701.898	

Streams. The Sugar River defines the western boundary of the study area. The Sugar River is a dominantly spring-fed system with extensive riparian wetlands. Numerous springs exist along the stream (the significant ones are shown on Map 10). Water quality in the river is good and has generally improved (WDNR 1992-93[1]). The river has good dissolved oxygen concentrations, enough to support both a warm and cold water fishery. Biotic indices have revealed "good" to "very good" water quality conditions. A 1993 DNR biological classification survey indicates the river, from its headwaters to Frenchtown Road, supports a coldwater fishery. The entire Sugar River has also been designated an "Exceptional Resource Water" through the state's antidegradation policy (NR 102 and NR 207).

[1] Department of Natural Resources. 1992-93. Water Resources Management Files – Southern District

The primary water quality problems are the result of "nonpoint" or diffuse sources of pollution from agricultural and urban runoff. One indicator of stream quality conditions is the type of insects found living on the rocks and other stream bottom materials. Certain species are more tolerant than others to habitat and water quality conditions. The Hilsenhoff Biotic Index or HBI indicates the degree of organic enrichment in a stream by the types of insects living there. A 1997 survey of aquatic insects ranged from good to very good, indicating only some or slight organic pollution.

Water quality assessments are also made based on chemical data. Overall, the chemistry of the water measured during baseflow or dry weather conditions show none of the parameters are at levels of concern (WRM 1993[2], DCRPC 1999[3]). Some agricultural and dairy sources may contribute loading during storm events, or during baseflow if animals are allowed access to the water. However, the river seems able to assimilate these inputs with minor impacts on the overall quality.

The Sugar River possesses many values including recreation (fishing and boating), wildlife habitat, flood protection and scenic beauty. The Sugar River also serves as the principal water source to Lake Belle View and lies adjacent to the Military Ridge and Ice Age Trails. This provides excellent access for the public to appreciate and enjoy the extensive wetland and riverine complex.

Overall, the river also needs to be protected from the adverse impacts of development, particularly in the headwaters near Verona and Madison. Runoff from streets and parking lots, construction sites add sediments and pollutants to the stream and degrade habitat and water quality.

Task 3: Little baseflow monitoring data is available for the Sugar River. It is suggested that continuous baseflow monitoring be conducted on the Sugar River by the USGS to facilitate better informed conservation, protection, and planning for the stream.

Badger Mill Creek flows through the mid-section of the study area from USH 18/151 to its confluence with the Sugar River at the southwest edge of the study area. A tributary of the Badger Mill Creek (the Lower Badger Mill Creek) also flows underneath USH 18/151 at its intersection with STH 69 and joins the Badger Mill Creek a quarter-mile downstream from USH 18/151.

Lower Badger Mill Creek drains a large area on the west side of the City of Madison, portions of the Towns of Middleton and Verona, and the west side of the City of Verona. Upper Badger Mill Creek drains a large area in the southwest portion of the City of Madison, as well as portions of the Cities of Fitchburg and Verona and the Town of Verona. The watershed area for Badger Mill Creek is about 33 square miles. A large spring is located at the Military Ridge State Trail parking lot near old Highway PB, but springs and groundwater seepage areas occur more typically in the lower

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[2] University of Wisconsin – Madison. 1993. *The Upper Sugar River Basin in Transition: A Watershed Evaluation with Management Options.* Institute for Environmental Studies Water Resources Management Workshop.

[3] *Dane County Water Conditions and Problems.* Dane County Regional Planning Commission. 1999.

portion of the Creek, downstream from USH 18/151 (see Map 10). The MMSD's return of highly treated effluent to the Badger Mill Creek has provided needed baseflow (of about 3 million gallons per day) to the Creek. The effluent return has mitigated the substantial loss of natural baseflow as a result of increased impervious cover and groundwater recession in the watershed (simulated baseflow reduction from 2 cubic feet per second under pre-development conditions to 0.9 for year 2000 conditions. See Appendix 1).

Baseflow water quality data on the Badger Mill between 1995 and 1998 designated Badger Mill Creek (south of Verona) as a "somewhat impacted" stream. Recent (2001) DNR water quality monitoring of the stream indicates increased levels of chlorides, total and dissolved phosphorus, and dissolved ammonia. Fisheries assessment of Badger Mill Creek performed by the DNR in 2005 indicates "poor" IBI scores for both coldwater and warmwater species at Main Street, Bruce Street, and STH 69; and "very poor" IBI scores at the Lincoln Street footbridge and at old Highway PB. The survey did find cold water indicator species downstream of the Lincoln Street footbridge and temperatures that are tolerable to brown trout and mottled sculpin below Main Street. DNR (2001) and MMSD (2003) sampling of the stream showed Hilsenhoff Biotic Index (HBI) values ranging from "fair" at the Lincoln Street footbridge to "good" at Bruce Street and STH 69.

Based on recent data from Badger Mill Creek, the DNR *may* decide to persue a codified classification change for Badger Mill Creek to "cold water." Such a reclassification will involve public notices and hearings and may have implications on other plans with impacts on the Creek, such as a satellite wastewater treatment plant treating the wastewater that is generated in the Sugar River watershed (mostly from the Cities of Madison and Verona).

Wetlands. Map 4 shows wetlands associated with Badger Mill Creek and the Sugar River. These are groundwater discharge wetlands associated with significant springs providing baseflow to the Creek and the Sugar River. The wetland complex in the northwest corner of the study area, located between the Sugar River and USH 18/151 north of Valley Road, is a high quality wetland and habitat to threatened and endangered species and a "natural community" over 100 acres. This area is designated as a Dane County Natural Resource Study Area in the Dane County Park and Open Space Plan (see Map 6).

The remaining wetlands in the study area (along the Sugar River as well as Badger Mill Creek) need to be surveyed and their quality and significance assessed.

Task 4: A detailed ecological survey of the entire study area needs to be conducted to evaluate natural communities and critical and sensitive habitat areas and the needed buffers for their protection.

Land Use and Land Cover. Map 7 shows the land use and land cover for the study area in the year 2000 (2000 Land Use Inventory, DCRPC). A few residential lots exist along Riverside Road and Manhatten Drive off of STH 69. Otherwise, land use in the study area is mostly agricultural. Some areas of "open land" are shown in lowland and wetland areas adjacent to the Sugar River. Small areas of woodlands are also present near Locust Drive and in the southeast corner of the study area.

The Adverse Impacts of Development

Urban development increases the extent of impervious land cover (roofs, streets, parking lots). This increases the velocity and volume of stormwater runoff and causes the following changes:

- Greater fluctuations in water levels in streams, lakes, and wetlands
- Increased erosion of land and stream bed and banks
- More sediment and pollutants delivered to the water body
- Degraded habitat (e.g. gravel spawning areas filled with sediment; loss of vegetation and structure; reduced plant diversity in wetlands), or loss of habitat (e.g. loss of riparian habitat due to erosion)
- Increased water temperature and loss of temperature sensitive coldwater fish
- Decline in aquatic insect diversity
- Decline in fish diversity
- Reduced natural reproduction and numbers of species

In addition, impervious land cover affects groundwater quality and quantity in the following ways:

- Prevents filtration and natural biological processes that remove nutrients and other pollutants when water percolates through the ground.

- Inhibits natural groundwater recharge, as well as subsequent groundwater discharge to surface waters (reducing stream baseflow, and drying up springs, wetlands, and streams).

Impervious cover is a major contributor to the environmental impact of urbanization. As the natural landscape is paved over, a chain of events is initiated that typically results in degraded water resources. The chain begins with changes to the hydrologic cycle, or the way water is transported and stored.

Major categories of non-point source pollutants introduced through urban runoff include fertilizers, pesticides, oil and volatile organic compounds, heavy metals and other toxic contaminants, pathogens, sediment and debris. Overabundance of nutrients such as phosphorus and nitrogen can lead to algal blooms in surface waters, resulting in suppressed life-sustaining oxygen levels in the water.

Impact Mitigation Possibilities

Wetland, Floodplain, Stream, and Upland Habitat Protection. A review of studies regarding recommended buffer widths shows a wide range depending on the purpose of the buffer (Castelle, A.J., A.W.Johnson, and C.Conolly. 1994. *Wetland and Stream Buffer Size Requirements—A Review.* Journal of Environmental Quality 23:878-882.). The recommended size for stream and wetland buffer ranges from 10 feet to 650 feet. The former only filters sediment out of the stormwater runoff from the stream bank areas, and the latter provides water quality a well as wildlife (mostly upland mammalian species) habitat protection. In most cases, a buffer width of 100 feet is adequate.

The wetlands and streams of the study area and the springs and groundwater seeps that maintain and support them are sensitive resources. These resources require buffer widths that provide filtration for runoff from a large upland area, thermal buffer for this runoff, and the protection of the upland areas associated with the springs and seeps that support the wetland areas. Furthermore, because of the habitat value of the stream and wetland areas, the buffer needs to provide the necessary upland habitat for water dependent upland species. It is proposed that a *minimum* vegetative buffer width of 300 feet be used for the streams, springs, wetlands, and the 100-year floodplain areas of the study area. The results of the ecological survey noted in Task 3 should be used to augment this buffer area with critical habitat areas. Ultimately, the buffer area and the background resource area (spring, stream, wetland, floodplain, and critical habitat area) should become a conservancy area.

Task 5: A wetland survey needs to be performed to accurately identify wetlands and their boundaries in the study area.

Application of Best Stormwater Management Practices.

Best stormwater practices (BMPs) have been used in newly urbanizing areas in Dane County since the early 90's. These practices were initially recommended by the Dane County Regional Planning Commission as part of the *Dane County Water Quality Plan.* In some cases, where the development could have adverse water quality impacts on a sensitive resource, BMPs were required. As the effectiveness of BMPs became more clearly documented and established, all urbanizing areas in Dane County were required to implement BMPs to mitigate the adverse water quality impacts of development. Figure 1 summarizes the effectiveness of selected BMPs in removing conventional pollutants from urban runoff, and the extent to which these practices mitigate the adverse hydrologic impacts of development.

Figure 1

BMP	Peak Discharge Control: 2 Year Storm	10 Year Storm	100 Year Storm	Volume Control	Groundwater Recharge	Streambank Erosion Control
Extended Detention						
Dry	Usually Provided	Usually Provided	Usually Provided	Seldom or Never Provided	Seldom or Never Provided	Usually Provided
Dry w/Marsh	Usually Provided	Usually Provided	Usually Provided	Sometimes Provided w/Careful Design	Seldom or Never Provided	Usually Provided
Wet	Usually Provided	Usually Provided	Usually Provided	Seldom or Never Provided	Seldom or Never Provided	Usually Provided
Wet Pond	Usually Provided	Usually Provided	Usually Provided	Sometimes Provided w/Careful Design	Seldom or Never Provided	Seldom or Never Provided
Infiltration Trench						
Full Exfiltration	Usually Provided	Sometimes Provided w/Careful Design	Seldom or Never Provided	Usually Provided	Usually Provided	Usually Provided
Partial Exfiltration	Usually Provided	Usually Provided	Seldom or Never Provided	Usually Provided	Usually Provided	Usually Provided
Water Quality Trench	Seldom or Never Provided	Seldom or Never Provided	Seldom or Never Provided	Usually Provided	Usually Provided	Usually Provided
Infiltration Basin						
Full Exfiltration	Usually Provided	Sometimes Provided w/Careful Design	Seldom or Never Provided	Usually Provided	Usually Provided	Usually Provided
Infiltration/Detention	Usually Provided	Usually Provided	Usually Provided	Usually Provided	Usually Provided	Sometimes Provided w/Careful Design
Off-Line Basin	Seldom or Never Provided	Seldom or Never Provided	Seldom or Never Provided	Usually Provided	Usually Provided	Sometimes Provided w/Careful Design
Porous Pavement						
Full Exfiltration	Usually Provided	Sometimes Provided w/Careful Design	Seldom or Never Provided	Usually Provided	Usually Provided	Usually Provided
Partial Exfiltration	Usually Provided	Usually Provided	Sometimes Provided w/Careful Design	Usually Provided	Usually Provided	Sometimes Provided w/Careful Design
Water Quality	Seldom or Never Provided	Seldom or Never Provided	Seldom or Never Provided	Usually Provided	Usually Provided	Sometimes Provided w/Careful Design
Water Quality Inlet	Seldom or Never Provided	Seldom or Never Provided	Seldom or Never Provided	Seldom or Never Provided	Seldom or Never Provided	Seldom or Never Provided
Grassed Swale	Sometimes Provided w/Careful Design	Seldom or Never Provided	Seldom or Never Provided	Sometimes Provided w/Careful Design	Sometimes Provided w/Careful Design	Seldom or Never Provided
Filter Strip	Sometimes Provided w/Careful Design	Seldom or Never Provided	Seldom or Never Provided	Sometimes Provided w/Careful Design	Sometimes Provided w/Careful Design	Seldom or Never Provided

Seldom or Never Provided — Sometimes Provided w/Careful Design — Usually Provided

Derived from: Schueler, Thomas R. (1987). *Controlling Urban Runoff: A practical manual for plan and designing urban BMPs*

Comparison of Median Pollutant Removal Efficiencies Among Selected Practice Groups: Conventional Pollutants

		Median Removal Rate For Stormwater Pollutants (%)					
Practice Groups	N	TSS	TP	Sol P	Total N	Nitrate	Carbon
Detention Pond	2	7	10	2	5	3	(-1)
Dry ED Pond	6	61	19	(-9)	31	9	25
Wet Pond	30	77	47	51	30	24	45
Wet ED Pond	6	60	58	58	35	42	27
Ponds[a]	36	67	48	52	31	24	41
Shallow Marsh	14	84	38	37	24	78	21
ED Wetland	5	63	24	32	36	29	ND
Pond/Wetland	11	72	54	39	13	15	4
Wetlands	35	78	51	39	21	67	28
Surface Sand Filters	6	83	60	(-37)	32	(-9)	67
Filters[b]	11	87	51	(-31)	44	(-13)	66
Channels	9	0	(-14)	(-15)	0	2	18
Swales[c]	9	81	29	34	ND	38	67

N =Number of performance monitoring studies. The actual number for a given parameter is likely to be slightly less.
Sol P= Soluble phosphorus, as measured as ortho-p, soluble reactive phosphorus or biologically available phosphorus.
Total N = Total Nitrogen. Carbon = Measure of organic carbon (BOD, COD, or TOC).
[a]Excludes conventional and dry ED ponds.
[b]Excludes vertical sand filters and vegetated filter strips.
[c]Includes biofilters, wet swales and dry swales.

Two important reports based on research in Dane County have recently been published. Selbig et. al.[4] (see Appendix 2) is a study of the effectiveness of construction erosion practices used in the St. Francis residential development in protecting Brewery Creek, a cold water fishery. The development is on both sides of Brewery Creek in the Village of Cross Plains, Dane County, Wisconsin. Selbig et. al. find an overall improvement in the water quality of Brewery Creek as a result of the use of BMPs as the area of the development went from agricultural land use to the land disturbance phase and home construction phase of the St. Francis development.

It should be noted that the stormwater management measures used in the St. Francis development were all afterthoughts, and therefore this development should be regarded as a successful retrofit case. The plat of St. Francis had already been approved before it came to the DCRPC for amendment to the Cross Plains Urban Service Area, and the developer was unwilling to redesign the plat with water quality impacts in mind. Dane County and DCRPC staff tried to get the best stormwater quality management out of a plat design that was not particularly sensitive to the susceptible resources in the area. The results of this study show great promise in the potential of protecting the Sugar River and its associated habitats through a combination of sensitive development, best stormwater management practices, and conservancy land reservation.

The Potter, Lathrop, et. al. paper[5] (see Appendix 3) is a study of the effectiveness of alternative stormwater management practices in mitigating adverse impacts on receiving waters. The study outlines successful approaches to infiltration and thermal impact reduction (through infiltration and conveyance via grass swales). Development density (through conservation design) was found to play a significant role in minimizing adverse impacts of development.

Task 6. There is a need for the adoption Best Management Practices with higher standards aimed at the mitigation of the adverse impacts of development in the study area. The following standards are suggestions:

- ***Control of post-development runoff rates to pre-settlement rates for all storms up to and including the 100-year storm.***
- ***Control of post-development runoff volumes to pre-~~development~~*** settlement. ***volumes for all storms up to and including the 25-year storm (given the open space and conservancy area, even higher storms could be practicably targeted).***
- ***Water quality treatment (capture of the 5 micron particle) for all storms up to and including the 10-year storm (given the volume control target, even higher storms could be practicably targeted).***

[4] *Hydrologic, Ecologic, and Geomorphic Responses of Brewery Creek to Construction of a Residential Subdivision, Dane County, Wisconsin, 1999-2002.* W.R. Selbig, P.L.Jopke, D.W.Marshall, and M.J.Sorge, 2004, USGS.

[5] *Alternative Urbanization Scenarios for an Agricultural Watershed: Design Criteria, Social Constraints, and Effects on Groundwater and Surface Water Systems.* Richard C. Lathrop and Kenneth W. Potter, WDNR and UW-Madison.

- ***Inclusion of raingardens with an area equal to 15% of the total impervious area on residential lots.***
- ***Infiltration of clean rooftop runoff for up to a 2 year storm for all other development.***
- ***Use of grass infiltration swales.***
- ***Thermal impact reduction to the maximum extent practicable.***

Mapping and Identification of Areas of High Infiltration Potential.

As development alters the natural landscape, the percentage of land covered by impervious surfaces increases. As impervious coverage increases, the velocity and volume of surface runoff increases, with a corresponding decrease in infiltration into the ground. Groundwater infiltration and subsequent discharge or baseflow to streams is the lifeblood of these aquatic communities. An important objective in land use development is to infiltrate as much precipitation into the ground as possible; thereby reducing surface water runoff and associated pollutants, as well as preserving infiltration and baseflow discharge to streams and wetlands. Opportunities may be limited, however. The natural Infiltration potential of soils vary based on geophysical characteristics and properties. In some cases the infiltration potential may be enhanced by various engineering techniques that take advantage of more permeable soils found lower in the soil column. Areas possessing underlying sand and gravel deposits present excellent opportunities for accomplishing this and may be used to enhance infiltration above natural levels to compensate for the loss of infiltration in impervious areas.

In an effort to help guide development and stormwater management strategies, various maps were developed identifying areas of high natural infiltration and areas where infiltration might be improved through engineering. These areas provide important opportunities that should not be paved over but, rather, incorporated into development design to help mitigate the impacts of future development planned for the area. Other areas may be less critical in this regard.

Maps 10, 11, and 12 show areas of high infiltration potential and enhanced infiltration that might be realized through engineered soil mixtures incorporated into development planned in the Badger Mill Creek / Sugar River Study Area. The maps were derived from data obtained from the 1999 updated NRCS Dane County Soil Survey, slope information using GIS, in consultation and review by staff from the Community Analysis and Planning, and Land Conservation Divisions.

Map 10 represents relative infiltration as it occurs naturally, as the existing or the pre-developed condition. It is based on cumulative scores of the most limiting permeable layer in the soil column, depth to water table, depth to bedrock, and slope (Table 2). Depth to bedrock, and slope were determined to be somewhat less important factors and weighted accordingly.

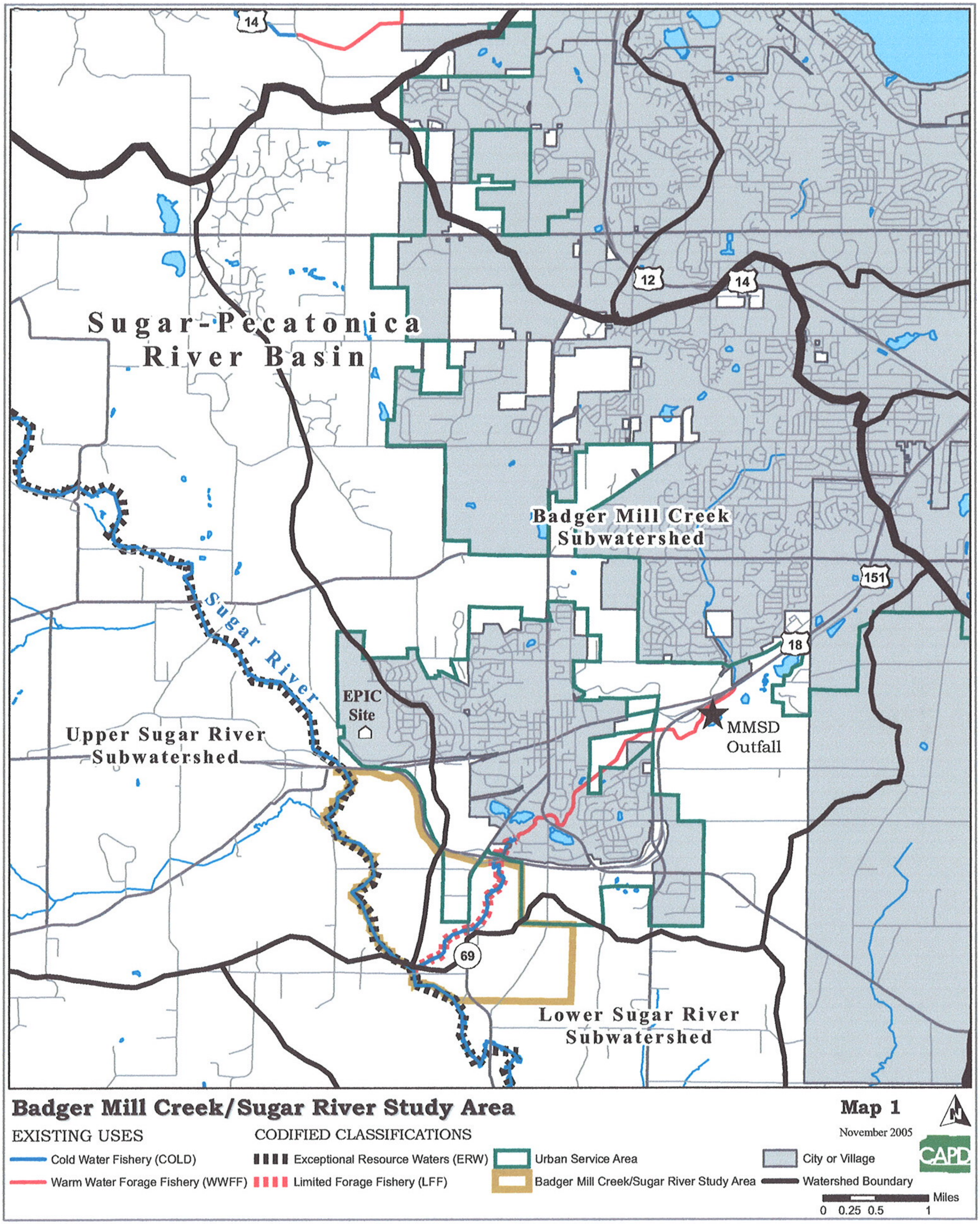
Table 2 Infiltration Rating Factors		
Criterion	**Criterion Groups**	**Score**
Permeability	0.06 to 0.2 in./hr. 0.2 to 0.6 0.6 to 2.0 2.0 to 6.0 6+	0 1 2 3 4
Depth to Water Table	0 – 3 ft. 3 – 5 5+	1 2 3
Depth to Bedrock	0 – 3 ft. 3 – 5 5+	0.5 1.0 1.5
Slope	0 to 4 percent 4 to 8 8+	1.5 1.0 0.5

Map 11 represents enhanced infiltration that may result from engineering practices. This was derived from the permeability in the lowest soil layer and assumes aggressive engineering/infiltration practices. For example, it is not unreasonable to place an engineered infiltration soil mixture in areas where less permeable layers exist. In many cases there is an underlying sand and gravel substratum within five feet of the ground surface which may be used to enhance infiltration. Note that the infiltration improves in some areas, compared to Map 10. These areas represent significant opportunities for addressing the stormwater impacts of development. Areas marked in gray have bedrock characteristics that are highly variable and would need to be determined through site specific analysis.

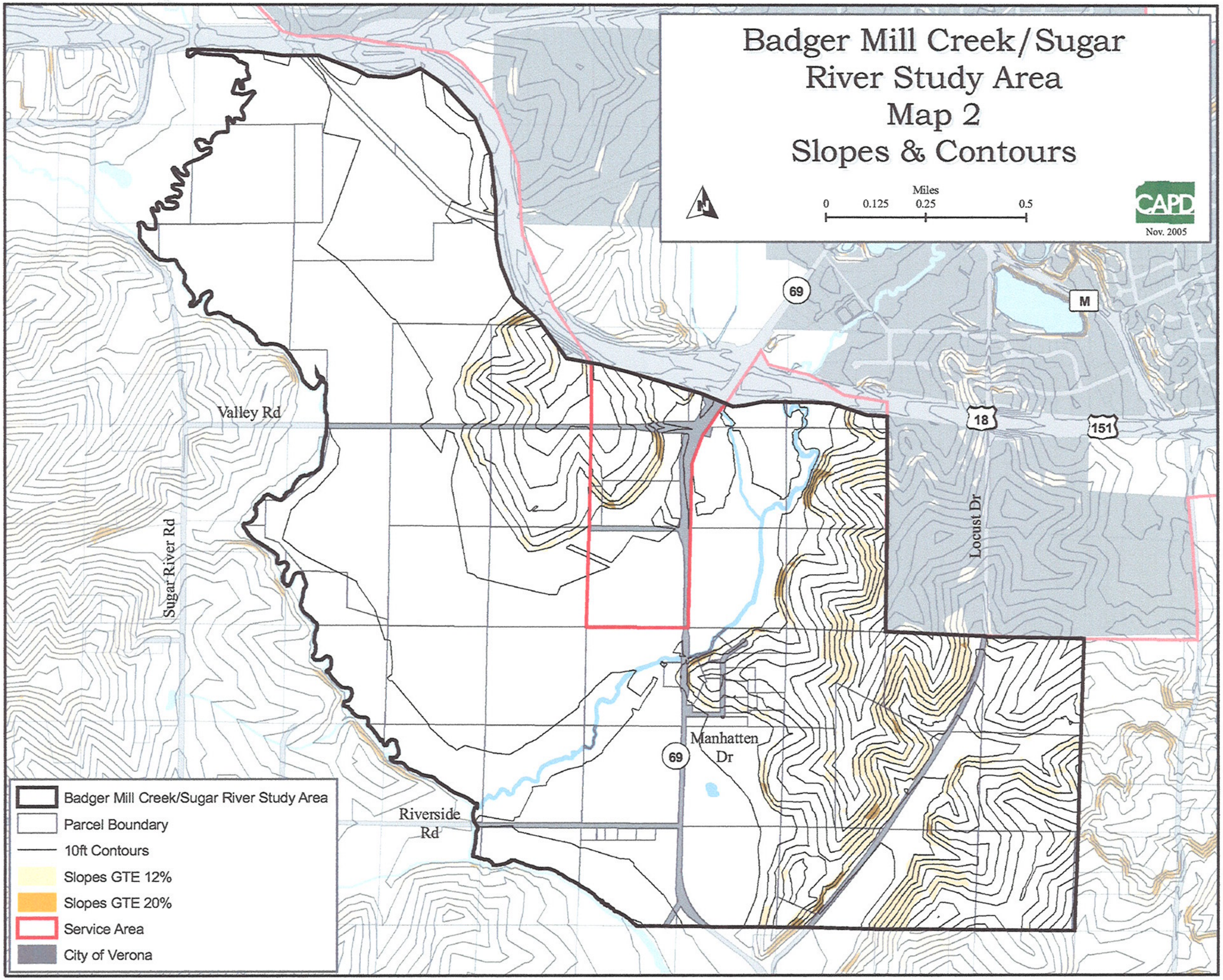
Map 12 highlights the areas where the enhancement potential may be the greatest. These areas showed the greatest difference in total scores between the natural and engineered states.

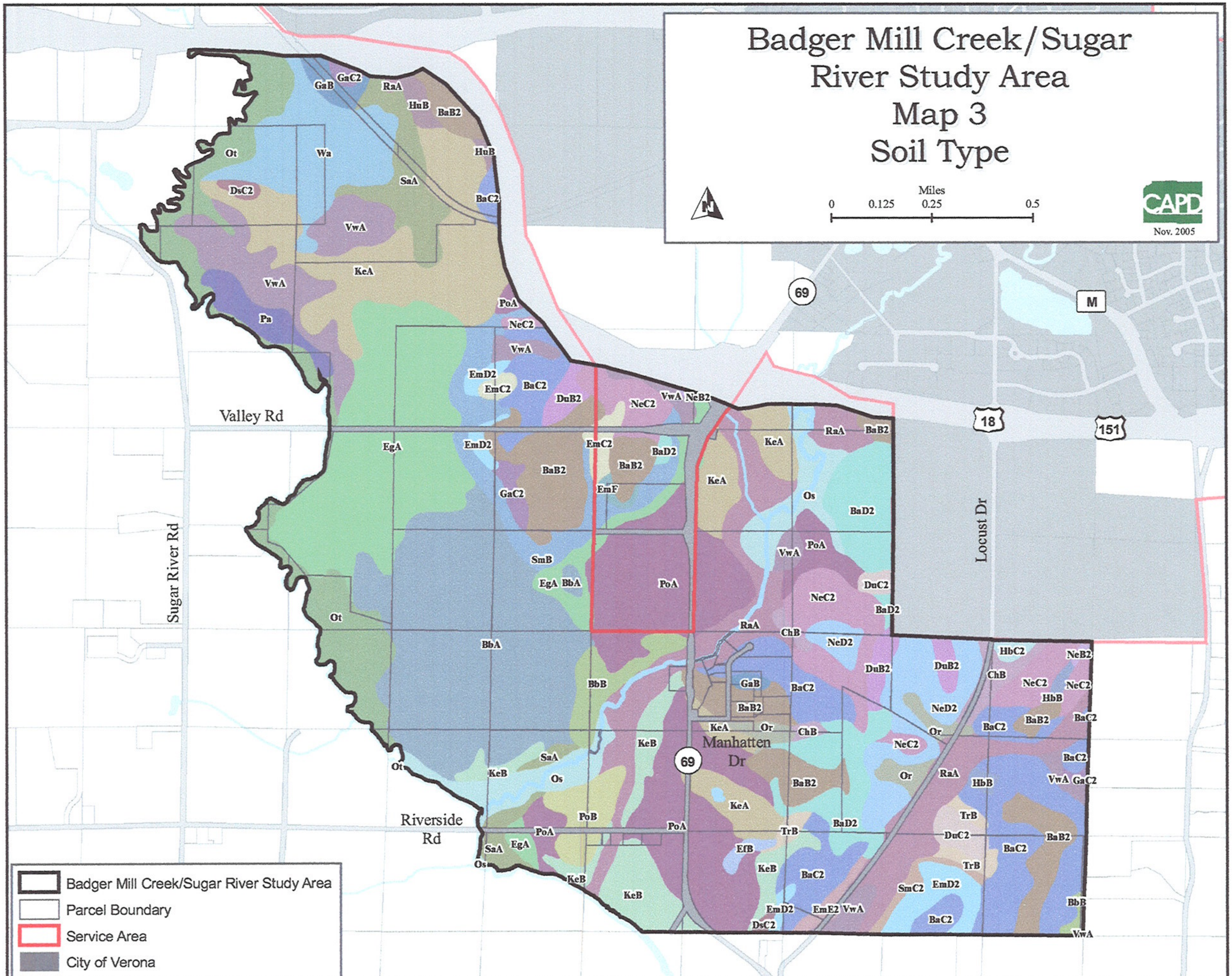
The maps support various strategies that may be pursued to help mitigate the impacts of future development planned in the area. Areas of naturally high infiltration should be maintained to the greatest extent possible. They are also prime locations for regional stormwater management facilities that could be used to infiltrate stormwater generated from development in other areas of the watershed. Furthermore, natural infiltration could be enhanced above natural levels by adding more pervious soil materials above sand and gravel deposits that may be present below. The maps show the areas where these opportunities exist. They are characterized as possessing high infiltration rates and high enhancement potential.

Other areas possess relatively fewer opportunities. Stormwater generated in these areas could be reduced on site to some extent, such as through rain gardens, but the majority will likely need to be routed to facilities down-gradient. These would need to be adequately sized/designed to accommodate the rates and volumes of water generated by the proposed development. In addition, the extent that runoff could be mitigated at the source will need to be determined by an analysis of the soils at a particular site. In some areas, particularly where there is shallow bedrock present, this cannot be adequately characterized by the limited information currently available (indicated in gray). Additional soils analysis will be needed to better characterize these areas and thus incorporate them into the stormwater management plans developed for this area.

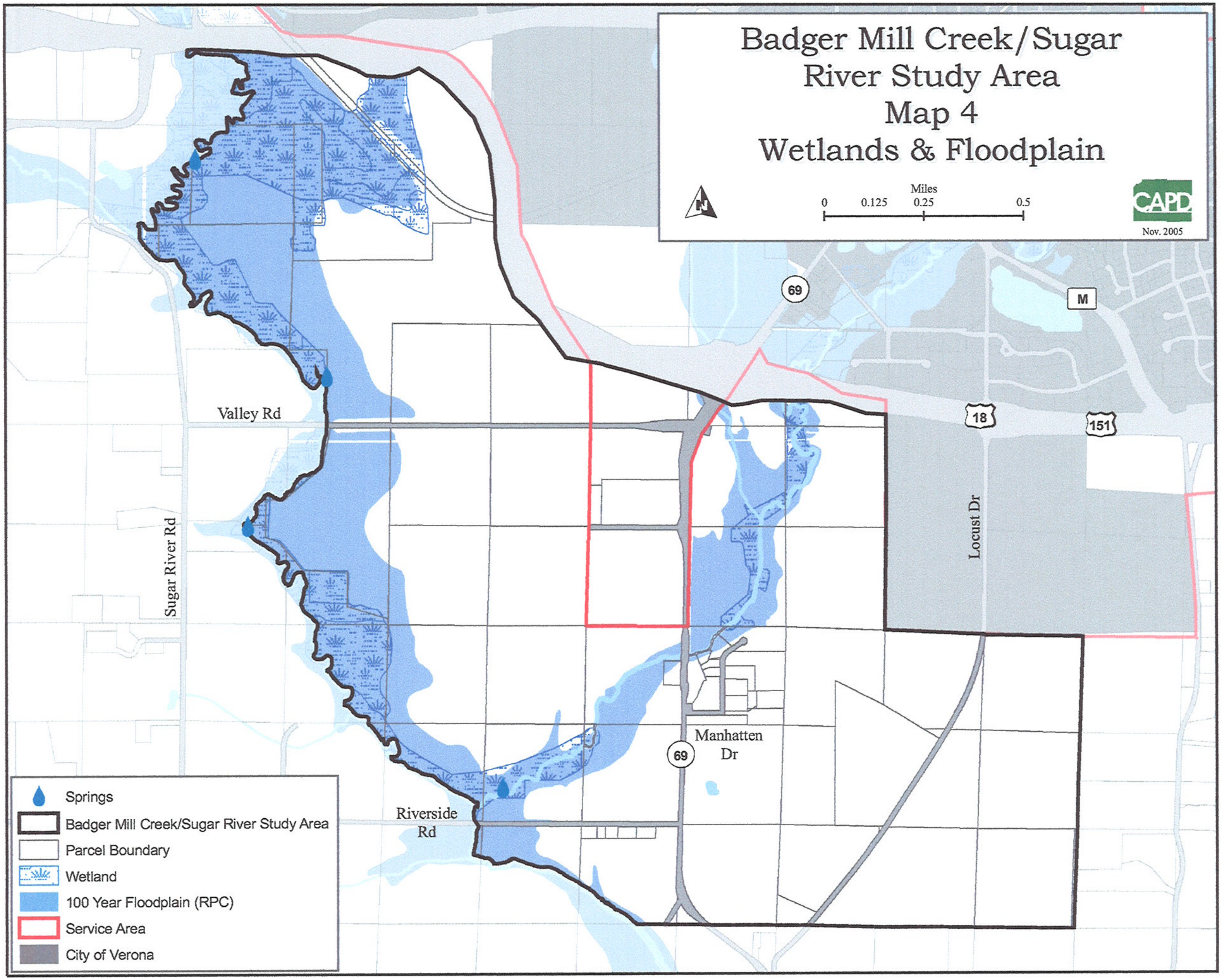


14
12
14
151
18
69
Sugar-Pecatonica
River Basin
Badger Mill Creek
Subwatershed
Sugar River
EPIC
Site
Upper Sugar River
Subwatershed
MMSD
Outfall
Lower Sugar River
Subwatershed
Badger Mill Creek/Sugar River Study Area
Map 1
November 2005
EXISTING USES
Cold Water Fishery (COLD)
Warm Water Forage Fishery (WWFF)
CODIFIED CLASSIFICATIONS
Exceptional Resource Waters (ERW)
Limited Forage Fishery (LFF)
Urban Service Area
Badger Mill Creek/Sugar River Study Area
City or Village
Watershed Boundary
0 0.25 0.5 1
Miles
CAPD

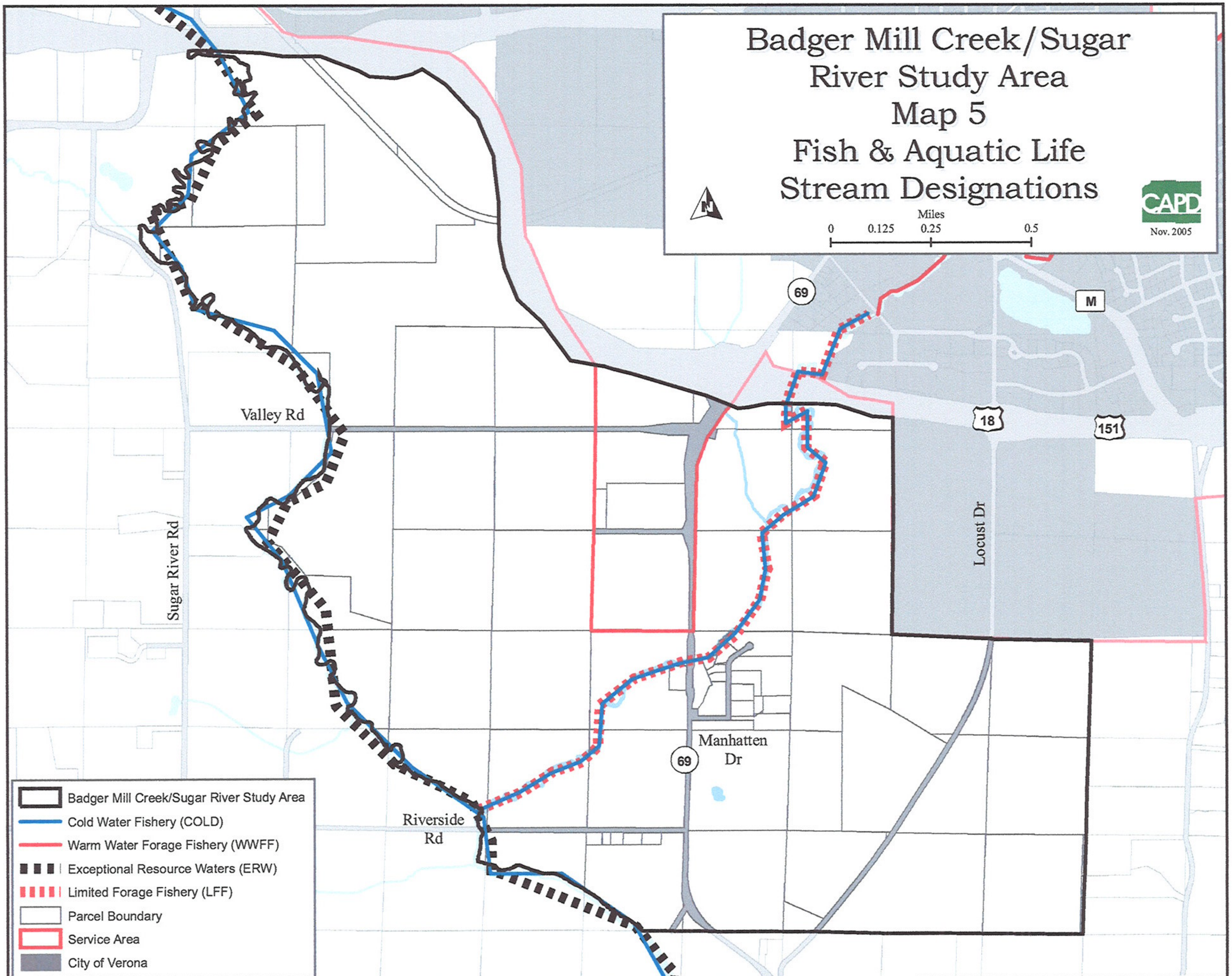

Badger Mill Creek/Sugar River Study Area
Map 2
Slopes & Contours
N
Miles
0
0.125
0.25
0.5
CAPD
Nov. 2005
69
M
18
151
Locust Dr
Valley Rd
Sugar River Rd
Manhatten Dr
69
Riverside Rd
Badger Mill Creek/Sugar River Study Area
Parcel Boundary
10ft Contours
Slopes GTE 12%
Slopes GTE 20%
Service Area
City of Verona

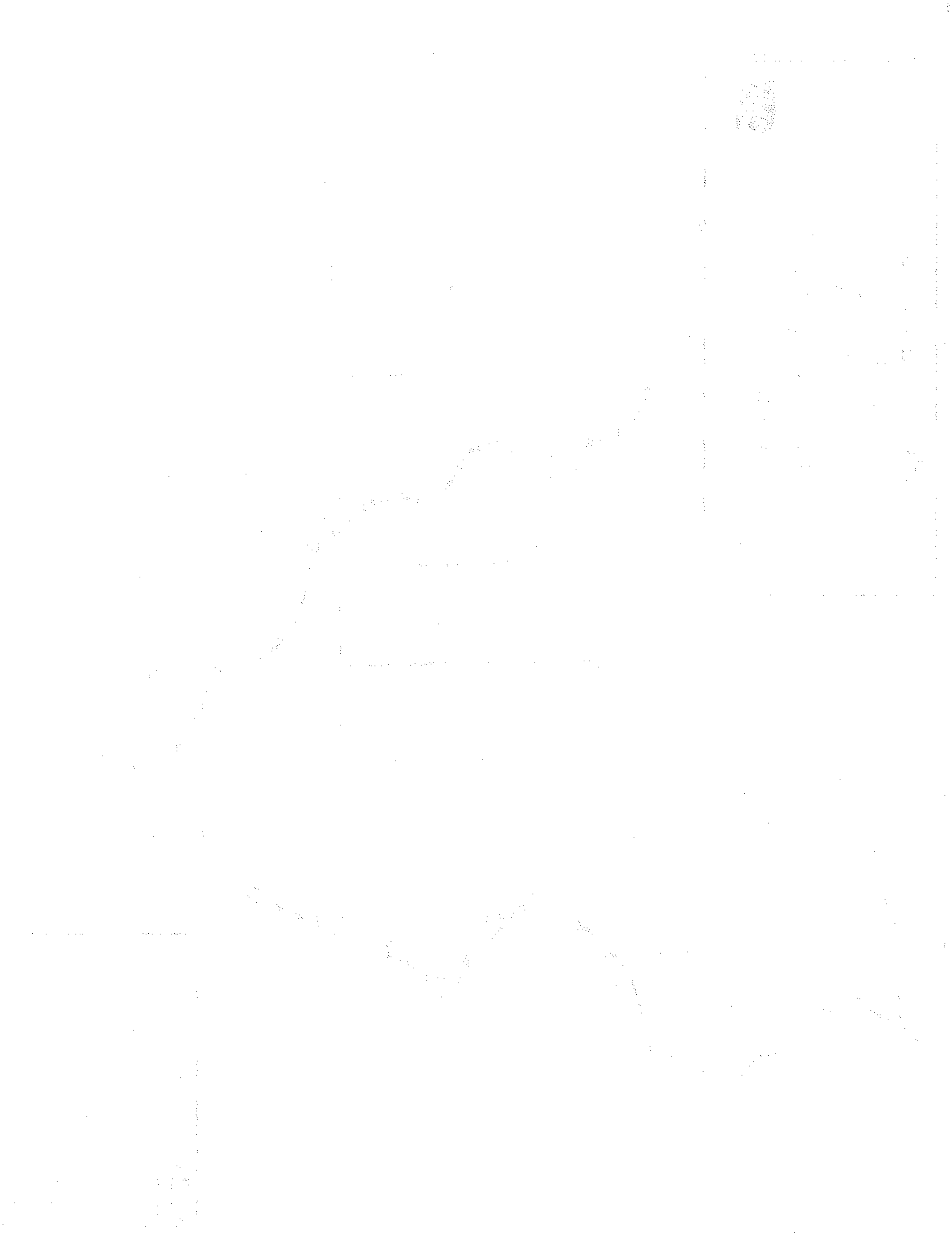


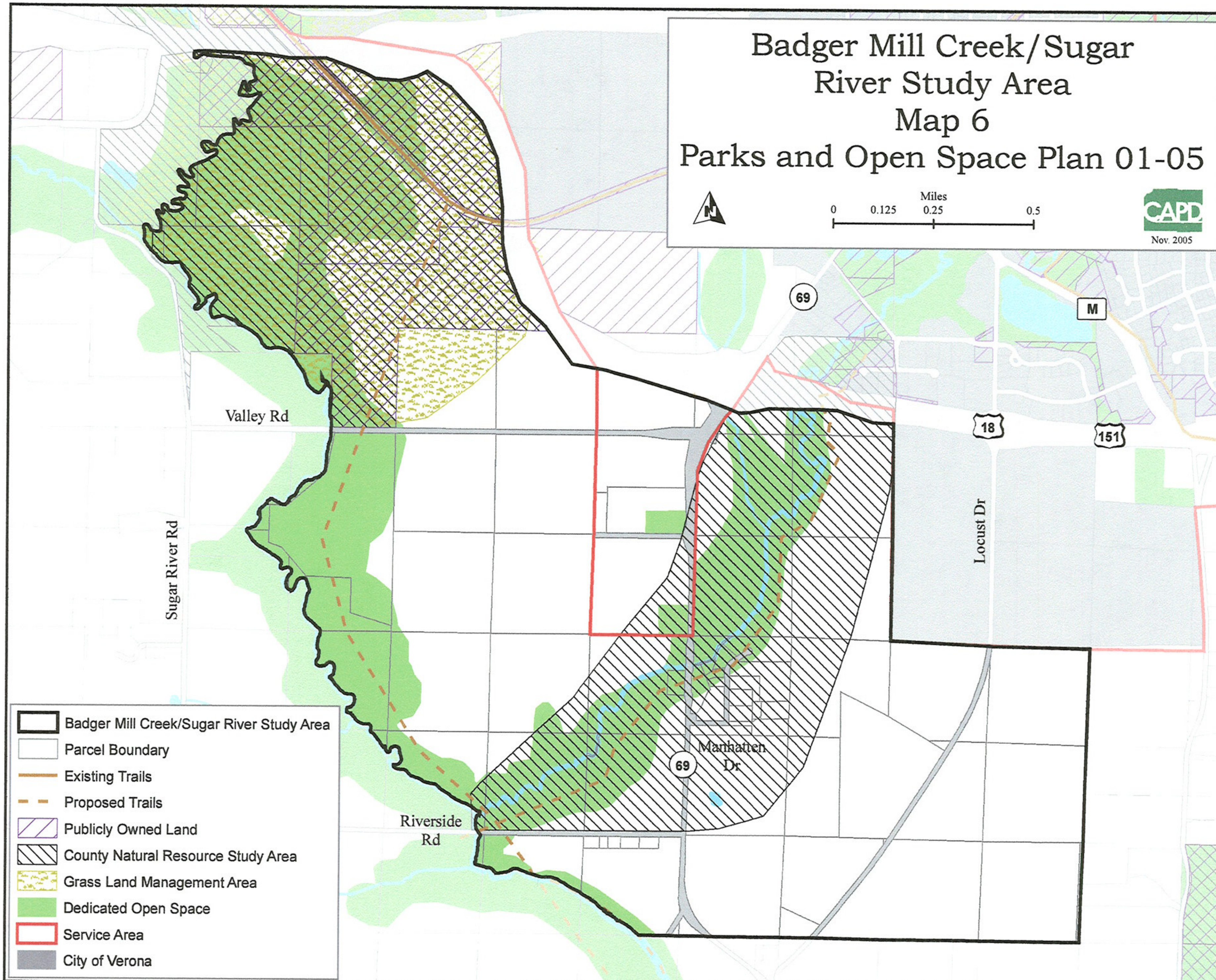
Badger Mill Creek/Sugar River Study Area
Map 3
Soil Type
Miles
0 0.125 0.25 0.5
CAPD
Nov. 2005
Valley Rd
Sugar River Rd
Riverside Rd
Manhatten Dr
Locust Dr
69
18
151
M
Badger Mill Creek/Sugar River Study Area
Parcel Boundary
Service Area
City of Verona



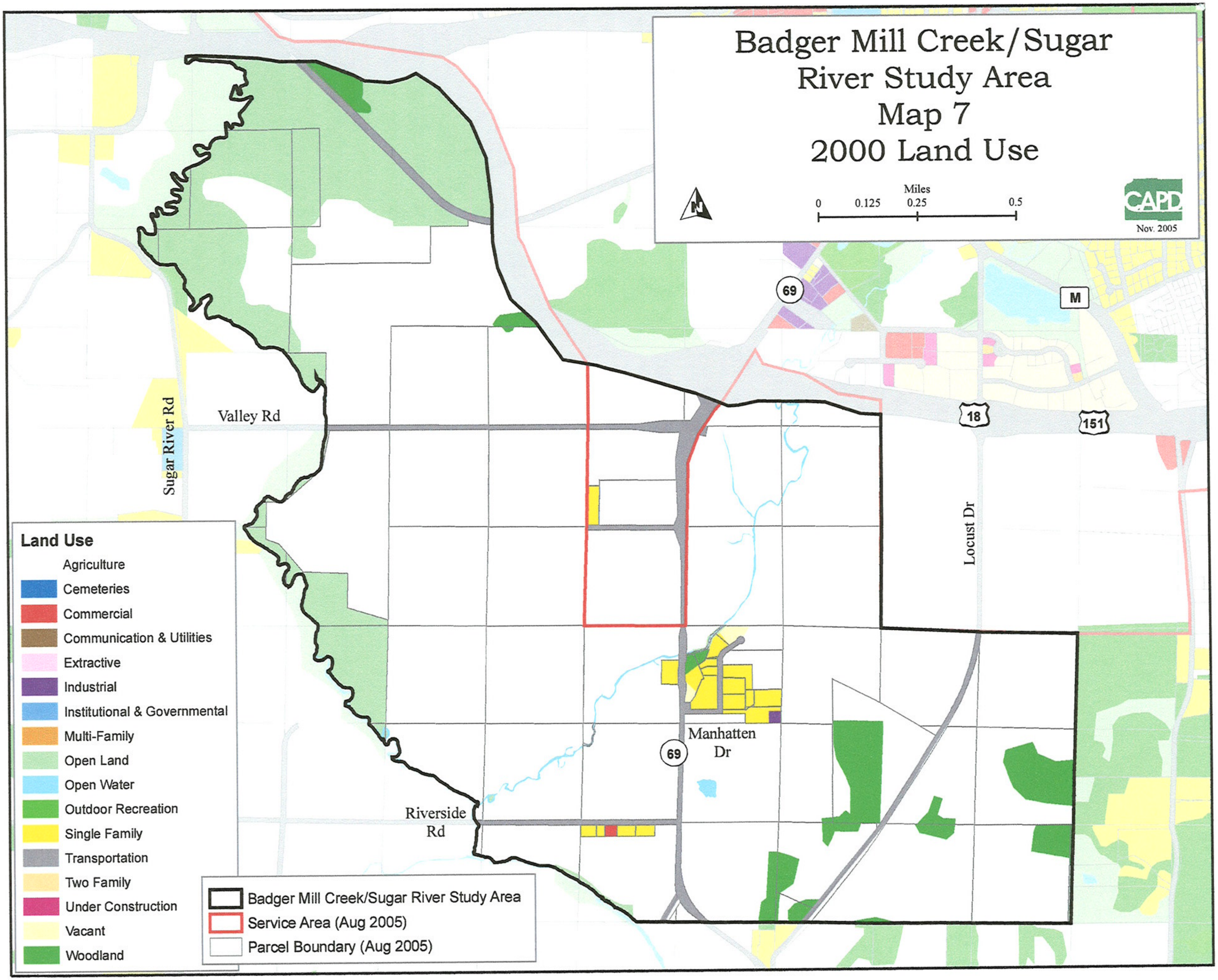
Badger Mill Creek/Sugar River Study Area
Map 4
Wetlands & Floodplain
Miles
0
0.125
0.25
0.5
CAPD
Nov. 2005
69
M
18
151
Valley Rd
Sugar River Rd
Locust Dr
Manhatten Dr
69
Riverside Rd
Springs
Badger Mill Creek/Sugar River Study Area
Parcel Boundary
Wetland
100 Year Floodplain (RPC)
Service Area
City of Verona


Badger Mill Creek/Sugar River Study Area
Map 5
Fish & Aquatic Life Stream Designations
N
Miles
0
0.125
0.25
0.5
CAPD
Nov. 2005
69
M
18
151
Valley Rd
Sugar River Rd
Locust Dr
Manhatten Dr
69
Riverside Rd
Badger Mill Creek/Sugar River Study Area
Cold Water Fishery (COLD)
Warm Water Forage Fishery (WWFF)
Exceptional Resource Waters (ERW)
Limited Forage Fishery (LFF)
Parcel Boundary
Service Area
City of Verona

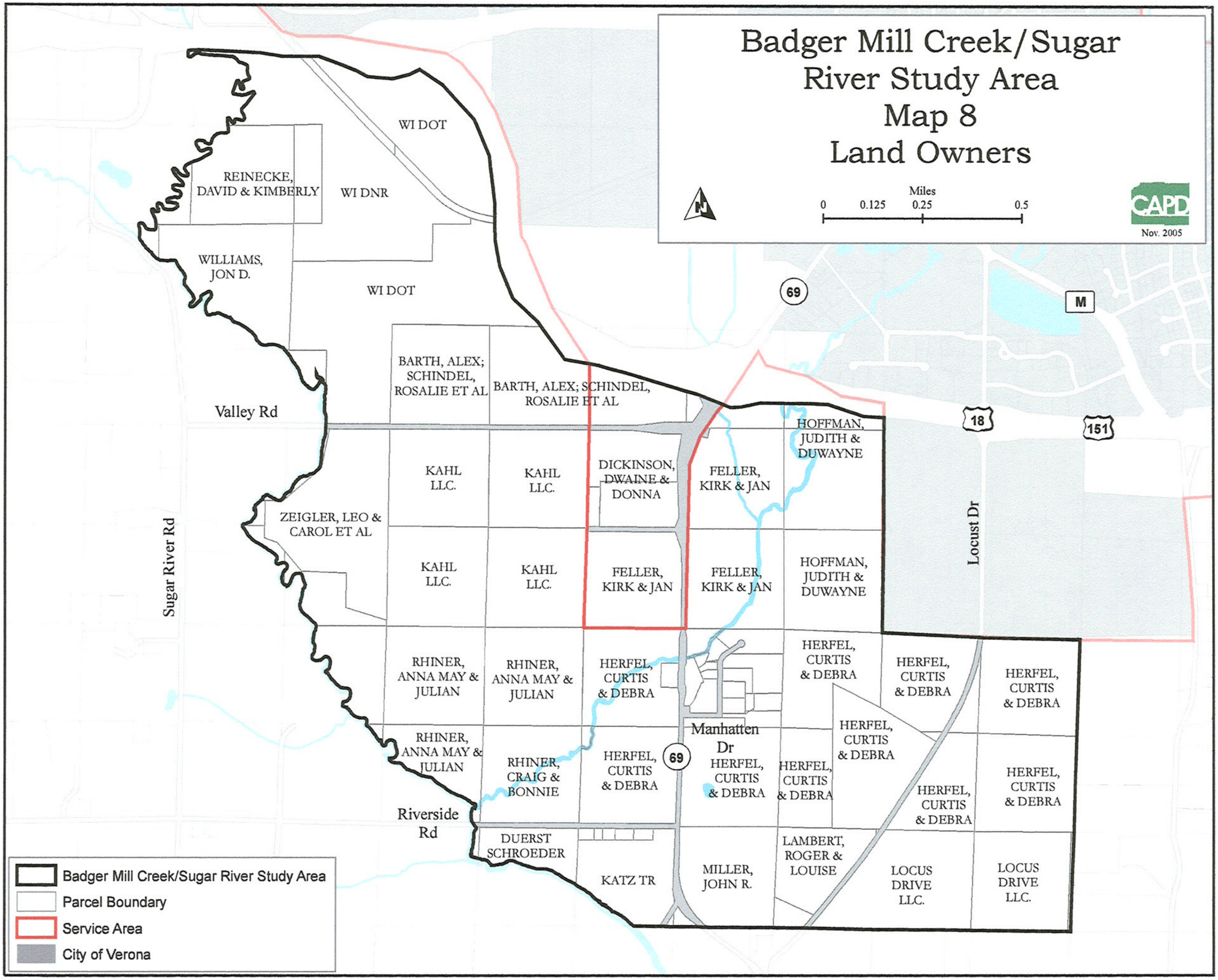




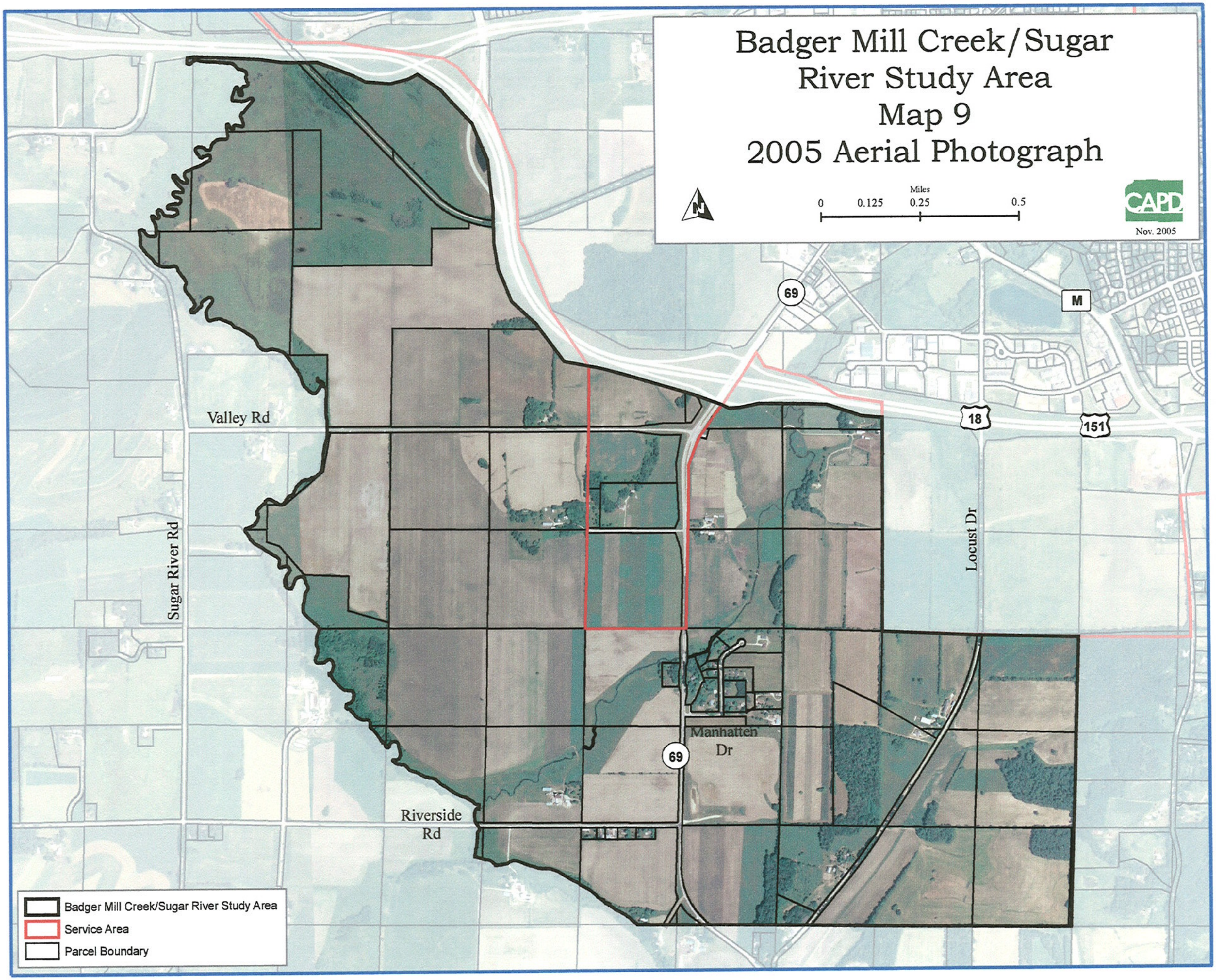
Badger Mill Creek/Sugar River Study Area
Map 6
Parks and Open Space Plan 01-05
Miles
0
0.125
0.25
0.5
CAPD
Nov. 2005
69
M
18
151
Valley Rd
Sugar River Rd
Locust Dr
Manhatten Dr
Riverside Rd
Badger Mill Creek/Sugar River Study Area
Parcel Boundary
Existing Trails
Proposed Trails
Publicly Owned Land
County Natural Resource Study Area
Grass Land Management Area
Dedicated Open Space
Service Area
City of Verona

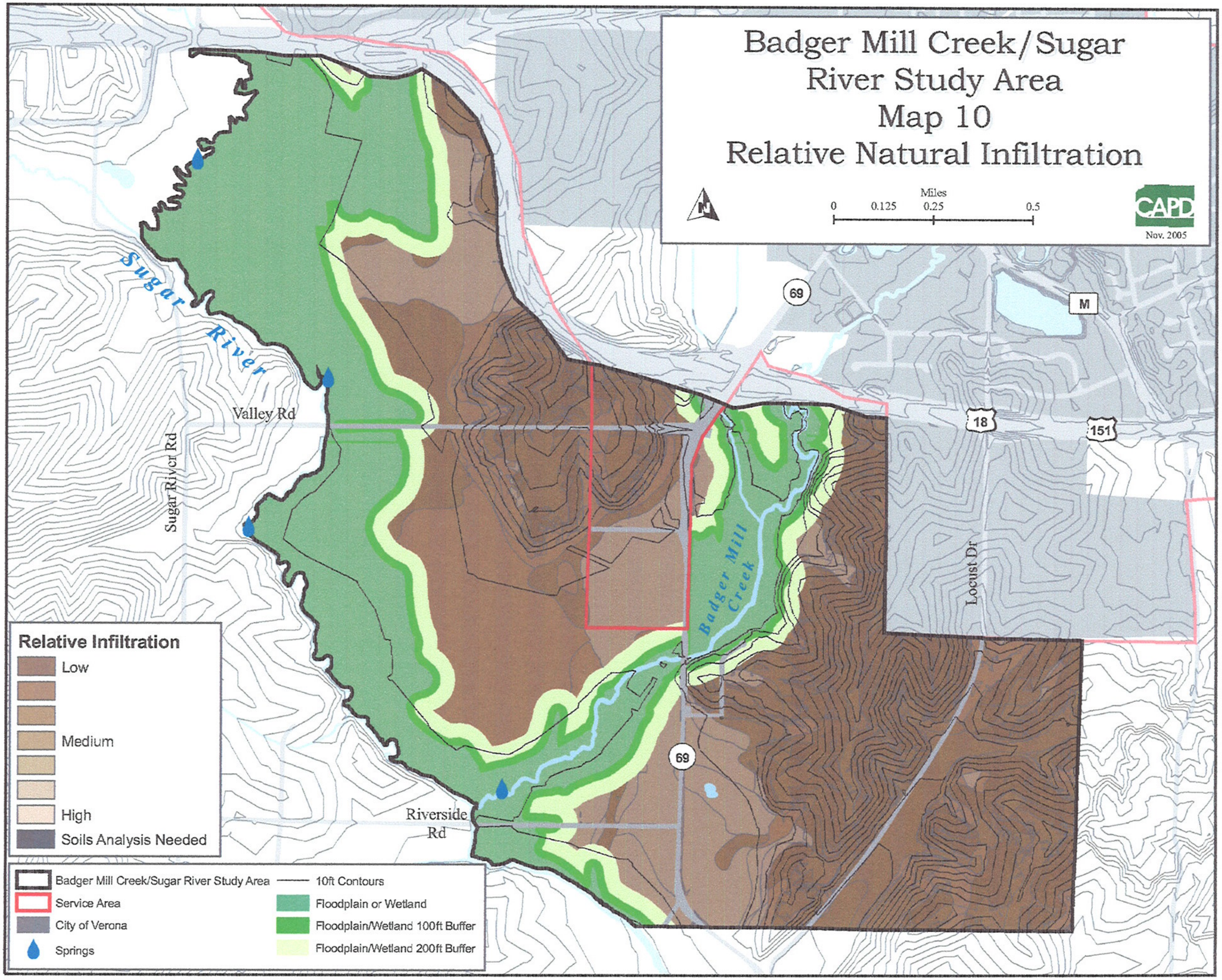


Badger Mill Creek/Sugar River Study Area
Map 7
2000 Land Use
N
Miles
0
0.125
0.25
0.5
CAPD
Nov. 2005
Valley Rd
Sugar River Rd
Locust Dr
Manhatten Dr
Riverside Rd
69
M
18
151
Land Use
Agriculture
Cemeteries
Commercial
Communication & Utilities
Extractive
Industrial
Institutional & Governmental
Multi-Family
Open Land
Open Water
Outdoor Recreation
Single Family
Transportation
Two Family
Under Construction
Vacant
Woodland
Badger Mill Creek/Sugar River Study Area
Service Area (Aug 2005)
Parcel Boundary (Aug 2005)

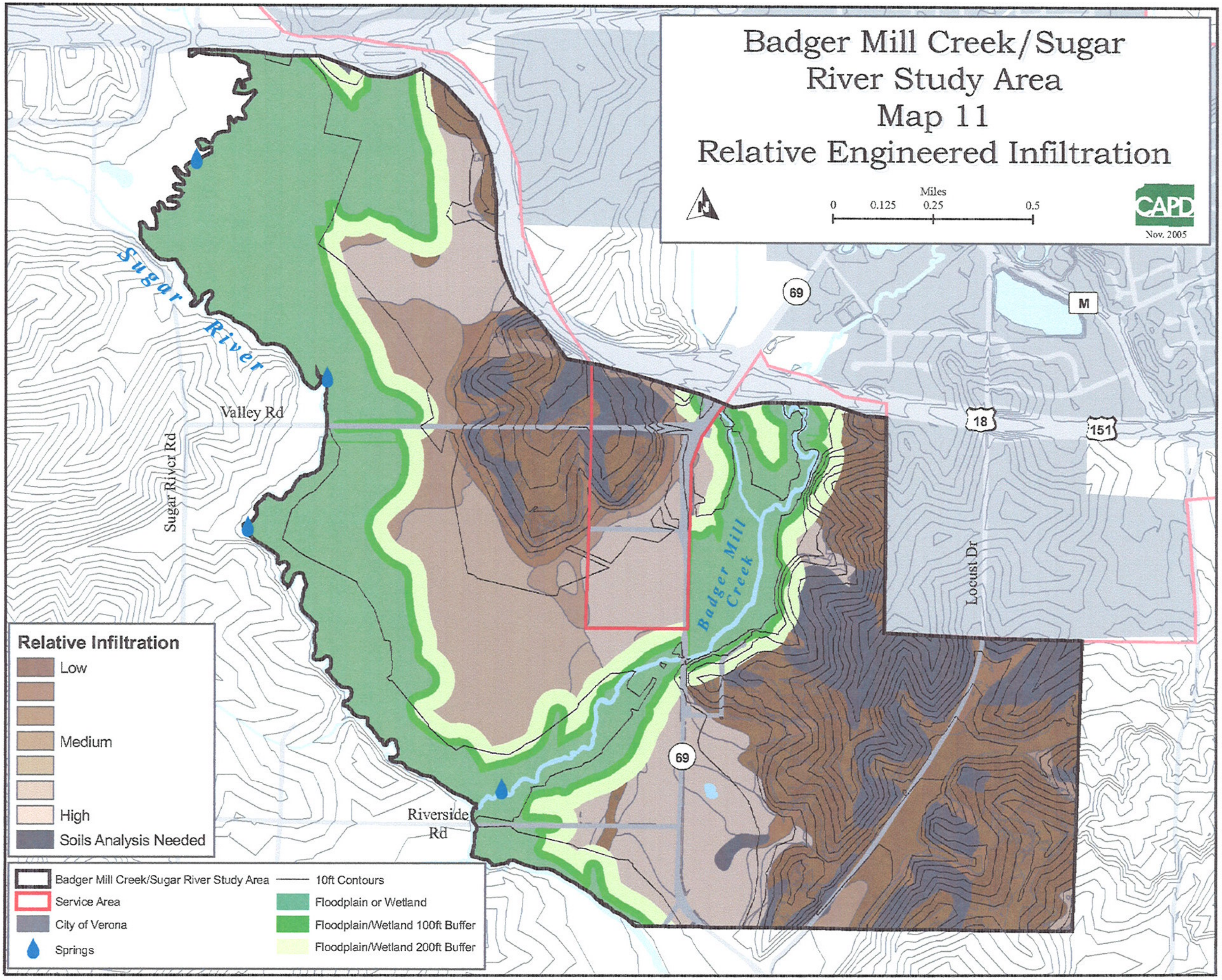


Badger Mill Creek/Sugar River Study Area
Map 8
Land Owners
Miles
0
0.125
0.25
0.5
CAPD
Nov. 2005
WI DOT
REINECKE, DAVID & KIMBERLY
WI DNR
WILLIAMS, JON D.
WI DOT
BARTH, ALEX; SCHINDEL, ROSALIE ET AL
BARTH, ALEX; SCHINDEL, ROSALIE ET AL
Valley Rd
KAHL LLC.
KAHL LLC.
DICKINSON, DWAINE & DONNA
FELLER, KIRK & JAN
HOFFMAN, JUDITH & DUWAYNE
ZEIGLER, LEO & CAROL ET AL
KAHL LLC.
KAHL LLC.
FELLER, KIRK & JAN
FELLER, KIRK & JAN
HOFFMAN, JUDITH & DUWAYNE
Sugar River Rd
Locust Dr
69
M
18
151
RHINER, ANNA MAY & JULIAN
RHINER, ANNA MAY & JULIAN
HERFEL, CURTIS & DEBRA
HERFEL, CURTIS & DEBRA
HERFEL, CURTIS & DEBRA
HERFEL, CURTIS & DEBRA
Manhatten Dr
RHINER, ANNA MAY & JULIAN
RHINER, CRAIG & BONNIE
HERFEL, CURTIS & DEBRA
69
HERFEL, CURTIS & DEBRA
HERFEL, CURTIS & DEBRA
HERFEL, CURTIS & DEBRA
HERFEL, CURTIS & DEBRA
HERFEL, CURTIS & DEBRA
Riverside Rd
DUERST SCHROEDER
KATZ TR
MILLER, JOHN R.
LAMBERT, ROGER & LOUISE
LOCUS DRIVE LLC.
LOCUS DRIVE LLC.
Badger Mill Creek/Sugar River Study Area
Parcel Boundary
Service Area
City of Verona

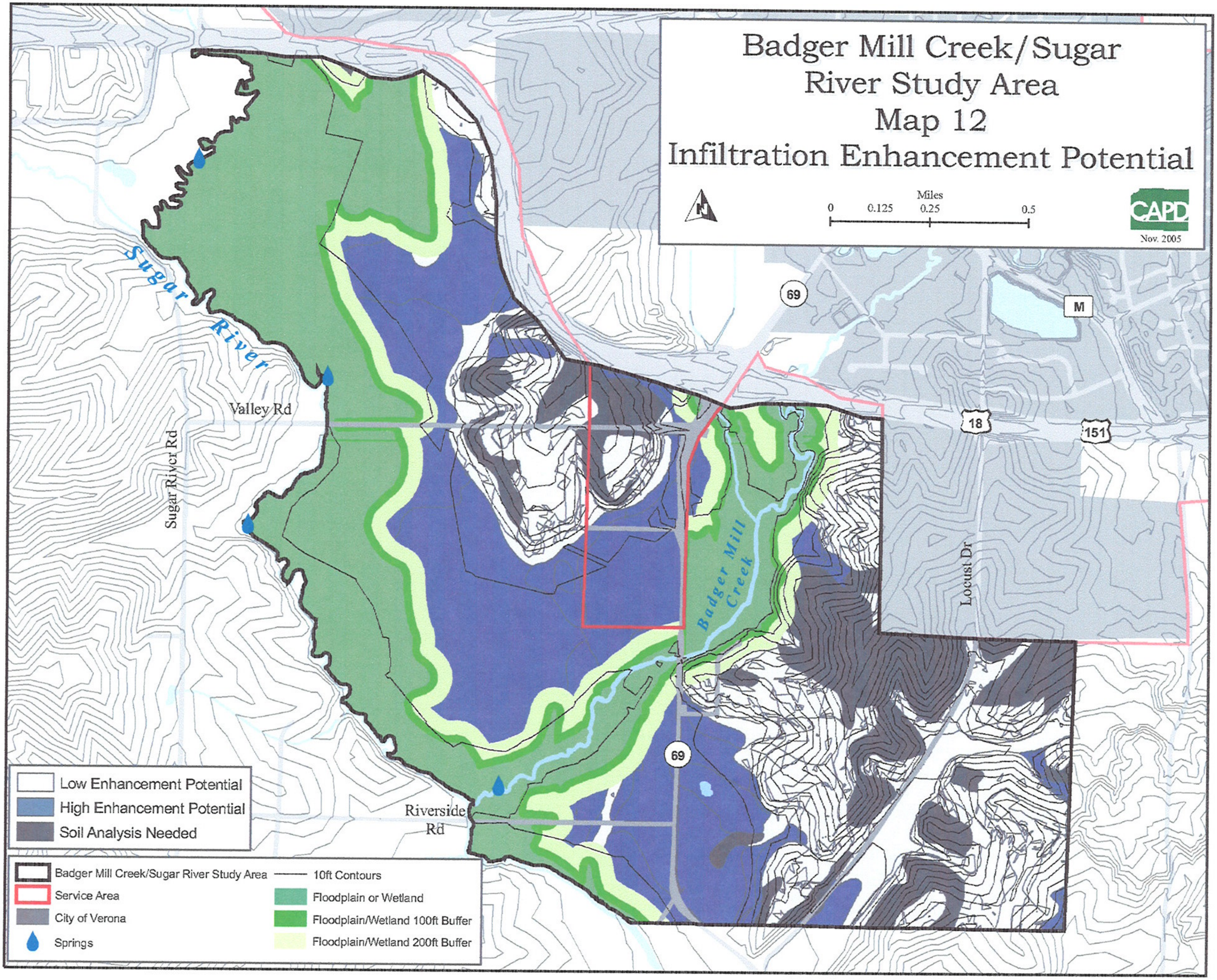

Badger Mill Creek/Sugar
River Study Area
Map 9
2005 Aerial Photograph
Miles
0
0.125
0.25
0.5
CAPD
Nov. 2005
69
M
18
151
Valley Rd
Sugar River Rd
Locust Dr
Manhatten Dr
69
Riverside Rd
Badger Mill Creek/Sugar River Study Area
Service Area
Parcel Boundary



Badger Mill Creek/Sugar River Study Area
Map 10
Relative Natural Infiltration
Miles
0
0.125
0.25
0.5
CAPD
Nov. 2005
Sugar River
Valley Rd
Sugar River Rd
Riverside Rd
Badger Mill Creek
Locust Dr
69
M
18
151
Relative Infiltration
Low
Medium
High
Soils Analysis Needed
Badger Mill Creek/Sugar River Study Area
Service Area
City of Verona
Springs
10ft Contours
Floodplain or Wetland
Floodplain/Wetland 100ft Buffer
Floodplain/Wetland 200ft Buffer



Badger Mill Creek/Sugar River Study Area
Map 11
Relative Engineered Infiltration
Miles
0
0.125
0.25
0.5
CAPD
Nov. 2005
Sugar River
Valley Rd
Sugar River Rd
Badger Mill Creek
Riverside Rd
Locust Dr
69
18
151
M
Relative Infiltration
Low
Medium
High
Soils Analysis Needed
Badger Mill Creek/Sugar River Study Area
Service Area
City of Verona
Springs
10ft Contours
Floodplain or Wetland
Floodplain/Wetland 100ft Buffer
Floodplain/Wetland 200ft Buffer


Badger Mill Creek/Sugar River Study Area
Map 12
Infiltration Enhancement Potential
Miles
0
0.125
0.25
0.5
CAPD
Nov. 2005
69
M
18
151
Locust Dr
Sugar River
Valley Rd
Sugar River Rd
Badger Mill Creek
Riverside Rd
Low Enhancement Potential
High Enhancement Potential
Soil Analysis Needed
Badger Mill Creek/Sugar River Study Area
Service Area
City of Verona
Springs
10ft Contours
Floodplain or Wetland
Floodplain/Wetland 100ft Buffer
Floodplain/Wetland 200ft Buffer

Appendix 1

USGS Fact Sheet (December 2001):
The Effects of Large-Scale Pumping and Diversion
on the Water Resources of Dane County, Wisconsin

The Effects of Large-Scale Pumping and Diversion on the Water Resources of Dane County, Wisconsin

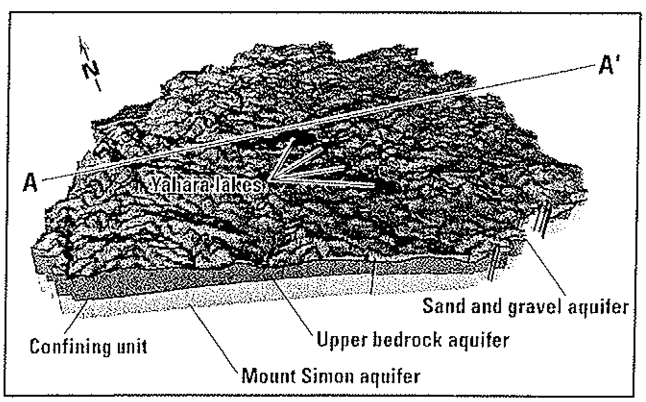
Introduction

Throughout many parts of the U.S., there is growing concern over the effects of rapid urban growth and development on water resources. Ground-water and surface-water systems (which comprise the hydrologic system) are linked in much of Wisconsin, and ground water can be utilized both for drinking water and as a source of water for sustaining lakes, streams, springs, and wetlands. Ground water is important for surface-water systems because it commonly has greater dissolved solids and more acid-neutralizing capacity than surface water or precipitation. The supplies of ground water are finite, however, and, in many cases ground water used for one purpose cannot be used for another. Moreover, ground-water use and withdrawal patterns may not be easy to alter once established. Thus, urban and rural planners are faced with decisions that balance the need for ground-water withdrawals while maintaining the quantity and quality of ground water for sustaining surface-water resources. Science-based information on the ground-water system and the connections to surface-water systems provides valuable insight for such decisions.

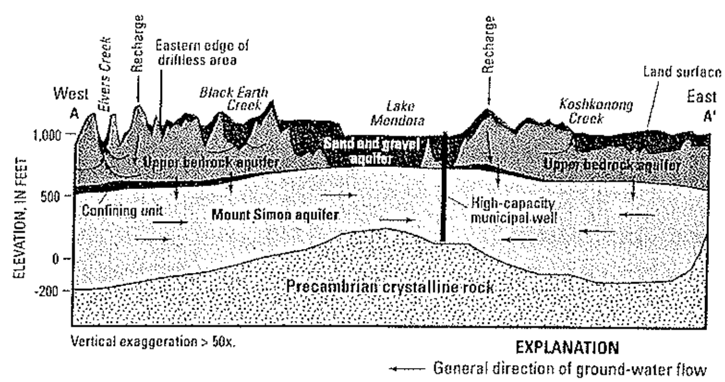
The regional hydrologic system in Dane County, Wisconsin, illustrates the effects of pumping and diversion on ground- and surface-water resources. Ground-water withdrawals from pumping average around 50 million gallons per day in the county, and ground water is the sole drinking-water supply for county residents. Large-scale pumping (large quantities pumped from wells distributed over a large area) is concentrated around the Madison metropolitan area and the Yahara lakes. Away from these pumping centers, ground water sustains lakes, streams, and wetlands, including important trout streams such as Black Earth Creek located in western Dane County. In an effort to improve the water quality of the Yahara lakes, the wastewater associated with the pumping is not returned to the areas where it was pumped but is diverted 9 miles south of the city of Madison. The pumping captures ground water that would normally discharge to the lakes; the diversion reintroduces the water far enough downstream that it does not re-enter the hydrologic system near the lakes. Dane County recently has had tremendous growth, and there is concern that the additional ground-water withdrawals needed to supply the larger population will adversely affect water-dependent ecosystems that are important for the local quality of life.

Dane County hydrologic setting

Bradbury and others (1999) describe the geologic and hydrogeologic setting for Dane County; a brief overview of this work is described here. Three aquifers and one confining unit underlie the Dane County area as shown in the block diagram (below). A shallow sand and gravel aquifer is made up of glacial and alluvial materials overlying the bedrock. Except in narrow alluvial valleys, the sand and gravel aquifer is thin or absent in western Dane County (called the "driftless area"). The upper bedrock aquifer underlies the unlithified deposits and overlies the Eau Claire Formation. The upper bedrock aquifer is made up of Cambrian sandstone and dolomite. A shale, which is part of the Eau Claire Formation, forms a confining unit at the base of the upper bedrock aquifer. This confining unit largely is absent in the pre-glacially eroded valleys of the Yahara lakes area and northeastern Dane County. Beneath the confining unit, a lower bedrock aquifer (the Mount Simon aquifer) overlies Precambrian crystalline basement rock. The Precambrian crystalline basement rock is assumed to be impermeable and forms the lower boundary of the ground-water-flow system.



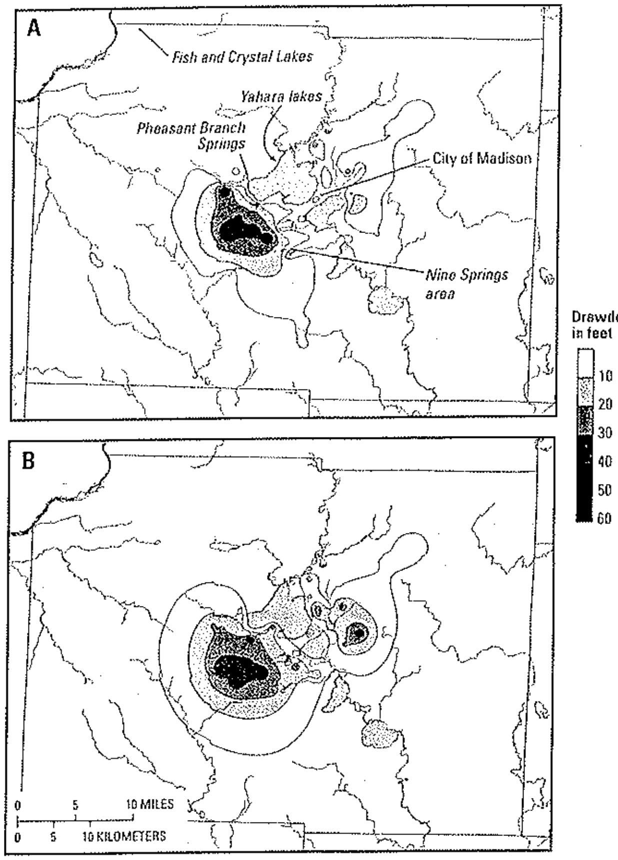
Block diagram showing the model domain and hydrostratigraphy used in the Dane County Regional Model. Much of the geologic detail is consolidated into three major aquifers and one confining unit.



West-East cross section showing the upper aquifers and the lower (Mount Simon) aquifer. Schematic flow-lines also are included to illustrate the local and regional ground-water flow that occurs in the county.

Precipitation-derived water enters the ground-water system as recharge to the water table. This recharge takes place primarily in upland areas throughout Dane County. Rates of recharge are variable because of differing soil percolation rates, slope, and relative position in the landscape. As shown in the cross section, local ground-water systems with short flow paths are common in the sand and gravel and upper bedrock aquifers; regional flow with longer flow paths are present in the Mount Simon aquifer. Some of the recharging water may move downward to the sand and gravel or upper bedrock aquifers, travel a short horizontal distance, and then move upward to discharge in surface waters and wetlands. A relatively small portion of this recharge moves downward through the confining unit and into the Mount Simon aquifer. Because of the conductive nature of the Mount Simon aquifer and the presence of the nearly impermeable Precambrian rock, flow paths in the aquifer primarily are horizontal. Pumping wells extract water from both the Mount Simon and the overlying bedrock aquifer; this pumping captures a portion of the ground water that discharged to area lakes, streams, springs, and wetlands under pre-development conditions. In places where large withdrawals of ground water occur, streams and lakes may recharge the ground-water system.

In order to improve the understanding of the hydrologic system and the effects of increased ground-water use, a Dane County Regional Hydrologic Study was initiated. The study was a cooperative effort among the Dane County Regional Planning Commission, the Wisconsin Geological and National History Survey, and the U.S. Geological Survey. The study included the development of a regional ground-water flow model, which helps managers make informed water-resources decisions on an ongoing basis. The model helped identify major areas of ground-water recharge and discharge, estimate the amount of ground water discharging to surface-water bodies, and simulate ground-water flow direction and rates. Once the model was developed, it was used for assessing effects of future ground-water withdrawals and the effects of proposed water-management programs. The initial model was completed in 1995 and has been updated annually to incorporate current conditions and updated modeling codes and procedures. The purpose of this Fact Sheet is to describe how the model was developed and used.



Figures 1a and 1b. Simulated drawdown from pre-development conditions in the upper bedrock (fig. 1a) and Mount Simon (fig. 1b) aquifers resulting from high-capacity pumping at typical 1992 discharge rates. The Yahara lakes supply water to the wells, which splits the drawdown into two distinct cones of depression. Contour interval is 10 feet.

How ground-water flow models work

Understanding the ground-water-flow system can be difficult, so investigators commonly use mathematical models to simulate a simplified version of the system using computers. The computer code relies on two basic principles to perform simulations. The first is that water flows "downhill," or more exactly, from high potential to low potential. The second principle is that water cannot be created or destroyed; thus, what flows into the ground-water system must either flow out or be stored. Changes in storage are identified by changes in water levels within the system. Using these principles, as well as site geology and locations of streams and lakes in the area being studied, the hydrologic system is simplified and represented in a mathematical model. It should be noted that, whereas seemingly simple in principle and operation, ground-water modeling can be complex because of uncertainty in important model inputs such as properties of the material in the subsurface and timing of water additions and subtractions.

Model calibration

The ground-water flow model for the Dane County area was developed using the computer program MODFLOW (McDonald and Harbaugh, 1988). The model inputs included such variables as the amount of rain and snow that enters the ground-water system (that is, the amount of precipitation minus the amount of runoff to streams and the amount removed by evaporation and plant uptake). In addition, the locations of large wells, streams, and lakes in Dane County were entered into the model. The model was calibrated using 1992 pumping rates, and simulated ground-water levels and flows to or from the streams were compared to the ground-water levels and flows measured in the study area. Using a trial-and-error approach, the various model inputs were varied until model-simulated levels and flow approximated measured values. Measured-to-simulated ground-water levels from over 3,000 wells and measured-to-simulated flows in 13 streams were compared during the model calibration process.

Important surface-water features can be affected by ground-water pumping. One such feature is the Pheasant Branch spring shown above.

Model results: comparison of pre-development conditions to current conditions

Pre-development conditions were simulated by removing the pumping wells from the calibrated base model. This resulted in a representation of the hydrologic system before development that can be compared to current conditions to assess the effects of pumping on water resources.

As shown by contouring the simulated drawdown (the amount of water-level decline from predevelopment conditions caused by the pumping), the greatest effect of pumping on water levels results in the Madison metropolitan area. Shallow and deep ground-water levels in the vicinity of Madison declined more than 60 feet (fig. 1a and 1b). The largest declines are at the centers of two cones of depression that are split by the Madison lakes. Directly adjacent to and beneath these lakes there is no simulated drawdown of the water table and only about 10 feet of drawdown simulated in the Mt. Simon aquifer. Two distinct cones of depression indicate that these lakes are important sources of water to the pumping wells. This result is expected because the confining unit is absent or thin in this area and the aquifers are in good hydraulic connection with the lakes.

It is interesting to note that prior to the large-scale pumping and diversion associated with development, the lakes and wetlands within the Madison area primarily received ground water. These lakes and wetlands primarily lose water to the ground-water system as a result of present-day pumping and diversion (fig. 2). Moreover, the largest area where ground

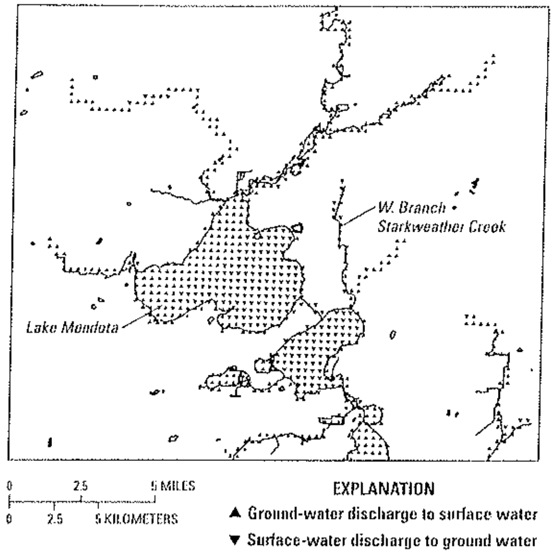


Figure 2. Model results showing the effects that pumping and diversion have had on the ground-water/surface-water interaction. During pre-development conditions, ground water would have flowed to the lakes, streams, and wetlands in the modeled area. Under 1992 conditions shown here, the lakes and streams lose water to the ground-water system (red triangles) in areas where development (and associated pumping and diversion) are concentrated.

water currently is discharging to a lake (the northwestern side of Lake Mendota) is relatively undeveloped. Because ground water is the sole source of drinking water for the county, additional pumping and diversion associated with future development in this undeveloped area could create a condition where Lake Mendota is losing water to the ground-water system on all sides. Such a change in the sources of water to the lake could affect the lake-water quality, food-web dynamics, and fish community.

The model also can be used to compare simulated pre-development baseflows to simulated current baseflows. It is apparent that pumping has reduced baseflow in streams (see table 1). That is, the current pumping and diversion near the city of Madison captures ground water that would contribute flow to these streams under pre-development conditions. The amount of baseflow decrease depends on how close to the pumping centers the stream is located. In one extreme case (W. Branch Starkweather Creek—see table 1), the stream is simulated as being dry for much of its length because of pumping and diversion. In reality, the stream flows during storm events but typically is dry during non-storm periods.

Table 1. Comparison of pre-development and current conditions simulated baseflows in selected Dane County, Wisconsin streams

Gaging station name	Simulated baseflow[1], in cubic feet per second	
	Pre-development	Current
Black Earth Creek at USGS gage above Black Earth	14.5	13.1
Badger Mill Creek at STH 69 south of Verona	2.0	0.6
E. Branch Starkweather Creek at Milwaukee St.	2.2	0.9
Koshkonong Creek at Bailey Rd. near Sun Prairie	0.6	0.1
Koshkonong Creek at Hoopen Rd. near Rockdale	36.4	33.8
Maunesha River south of USH 151	12.3	11.9
Mt. Vernon Creek at USGS Gage	2.4	2.1
Murphy (Wingra) Creek at Beld St.	3.4	1.3
Nine Springs at Hwy. 14	4.9	2.2
Pheasant Branch Creek at USH 12 at Middleton	2.7	1.2
Six Mile Creek at Mill Rd. near Waunakee	5.0	4.3
Token Creek at USH 51	13.0	10.6
W. Branch Starkweather Creek at Milwaukee St.	2.8	0.0
W. Branch Sugar River at STH 92 near Mt. Vernon	5.6	5.3
Yahara River at Golf Course near Windsor	8.8	8.0

[1] Baseflow is the part of streamflow because of ground water discharging to the stream.

Finding the contributing areas for drinking-water wells

Once the model is completed it can be used to trace mathematical water particles to determine where the ground water goes (if we track forward in time) or where it came from (if we track backward in time). This approach was used to simulate the area that supplies ground water to wells (called contributing areas). Model simulations indicate that, for the longest flowpaths, it can take many thousands of years for ground water to move from the area where it enters the ground to where it discharges to a well, stream, or lake. Particles were tracked backwards from each municipal well located in Dane County. The resulting contributing areas (fig. 3) illustrate that the source for ground water withdrawn by municipal wells in Dane County lies entirely within the county boundaries for almost every well.

Evaluating pumping scenarios

The model also can be used to evaluate the effects of different pumping scenarios on ground-water availability and their effect on water resources. The model developed for Dane County demonstrated that an adequate drinking-water supply is available for Dane County if no other uses for the ground-water resources are included. Model results also demonstrated that, depending on the distribution and rate of withdrawal of proposed and existing wells, water quality may be affected, wetlands may be lost, and baseflow in streams may be reduced substantially.

Two scenarios were simulated with the model based on water-use projections for the year 2020 (DCRPC, 1997). The scenarios are: 1) the central 50 percent of Madison municipal wells (inner ring of red dots in fig. 4) provide 75 percent of the daily water demand and the outer 50 percent of wells (outer ring of yellow dots in fig. 4) provide 25 percent, and 2) the central 50 percent of Madison wells provide 25 percent of the daily water demand and the outer 50 percent provide 75 percent. By providing the majority of water from the central wells (scenario 1), the major sources of water for the wells are lakes and wetlands near Madison; baseflows in rural

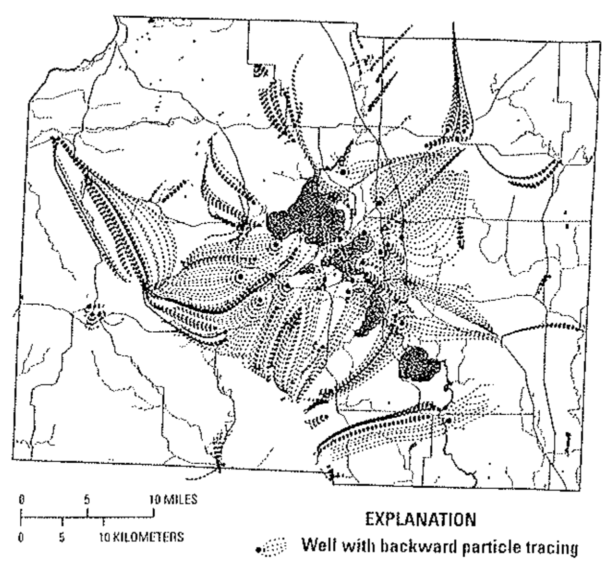
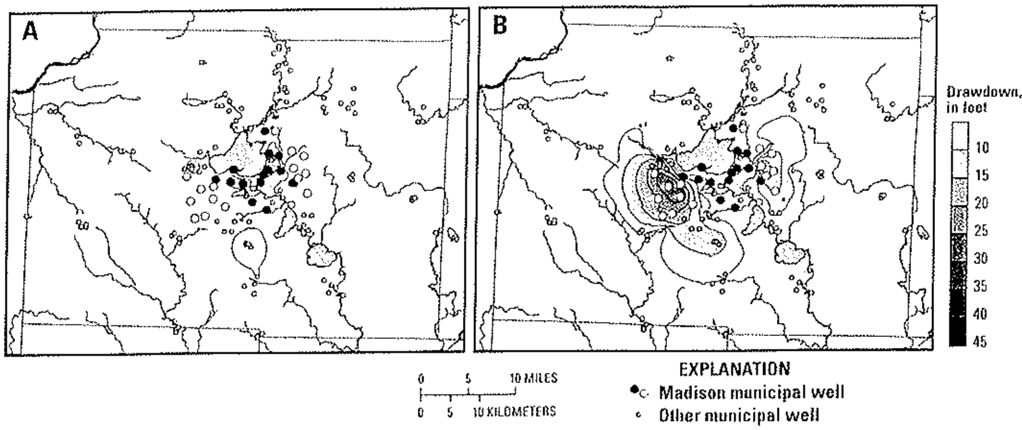


Figure 3. The areas that contribute water to the each municipal well in the county are simulated using backward particle-tracking (from the well to the recharge area) within the modeled system. The long particle paths represent a time of travel from the recharge area to the well on the order of thousands of years.

county streams are only slightly affected. Scenario 2 indicates that the wells would capture water that normally would flow to area wetlands and streams rather than removing water from the lakes. This result is demonstrated by the increased drawdown from 1992 conditions for scenario 2 (fig. 4b). The additional drawdown in the water table for scenario 2 is much greater than scenario 1, indicating that scenario 2 would have the greatest adverse effect on wetlands and streams in the county. These scenarios are for illustrative purposes only and do not account for the feasibility (economic, political, or other considerations) of implementing any particular pumping strategy. Such considerations would have to also be taken into account to fully assess the practicability of different strategies.



Figures 4a and 4b. The model can be used to simulate changes in the hydrologic system for a selected management scenario. In this example, the Madison municipal wells are divided into an inner ring (red dots) and outer ring (yellow dots). In 4a (scenario 1) the inner ring pumps 75 percent of the total water pumped and the outer ring pumps the remaining 25 percent; in 4b (scenario 2) the outer ring pumps 75 percent of the total water pumped and the inner ring pumps the remaining 25 percent. As shown, if the outer rings are required to supply 75 percent of the total water, there will be increased drawdown in the areas near the wells. There is much less drawdown from pumping the inner ring of wells because the water primarily is derived from the Yahara lakes (a relatively large source of water).

How this regional model has been applied to smaller site investigations

The Dane County ground-water-flow model is suitable for use as a tool for regional water management, but because of its regional focus, the model should not be used for site-specific simulation. However, the model provides a valuable framework within which site-specific studies can be carried out. The following are examples of ongoing site-specific studies that have made use of the Dane County model.

Pheasant Branch Watershed – The Dane County model was used for a smaller-scale ground-water/surface-water modeling study done by the U.S. Geological Survey, in cooperation with the City of Middleton and the Wisconsin Department of Natural Resources. The study focused on the effects of urbanization on streamflows and spring flows (Hunt and Steuer, 2000; Hunt and others, 2001; Steuer and Hunt, 2001), and the models are now part of a large watershed-scale project conducted by the Wisconsin Department of Natural Resources, University of Wisconsin – Madison, Wisconsin Geological and Natural History Survey, and U.S. Geological Survey.

Nine Springs Watershed – The Nine Springs watershed, located just south of the City of Madison (fig. 1a), contains an unusually large concentration of cold-water springs and associated wetlands. The Dane County model was used as a starting point for the construction of a detailed inset model to investigate these springs and to determine the effects nearby land-use changes may have on the springs and wetlands (Swanson, 2001). Model simulations helped quantify anticipated reductions in spring discharge resulting from nearby ground-water withdrawals and simulated the land-surface area contributing recharge to the springs. This information is critical for making land-use decisions to protect the quality and quantity of spring discharge.

Fish and Crystal Lakes – Elevation of the stage of Fish and Crystal Lakes, located in northwestern Dane County (fig. 1a), has increased 9 feet since 1966 and caused flooding of some near-shore residences. By using the Dane County model as a starting point, a new U.S. Geological Survey computer program that simulates lakes was coupled to a model of the ground-water system and was used to determine that increasing ground-water recharge was responsible for the lake-stage increase. The model was then used to simulate how pumping from Fish Lake would lower the stage of both lakes and how the lake stages would recover when pumping was stopped (Krohelski and others, 2001).

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Information

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Appendix 2

USGS Scientific Investigations Report 2004:
Hydrologic, Ecologic, and Geomorphic Responses of
Brewery Creek to Construction of a Residential
Subdivision, Dane County, Wisconsin, 1999-2002

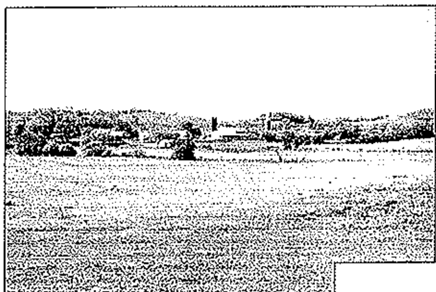
Appendix 2

USGS Scientific Investigations Report 2004:
Hydrologic, Ecologic, and Geomorphic Responses of Brewery Creek to Construction of a Residential Subdivision, Dane County, Wisconsin, 1999-2002

In cooperation with the Dane County Land Conservation Department
and the Wisconsin Department of Natural Resources

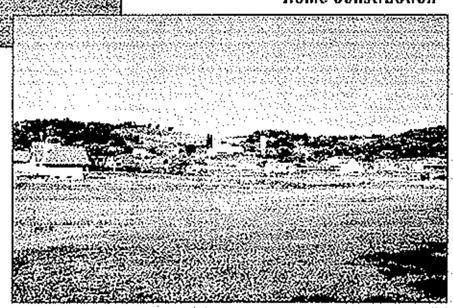
Hydrologic, Ecologic, and Geomorphic Responses of Brewery Creek to Construction of a Residential Subdivision, Dane County, Wisconsin, 1999–2002

Preconstruction



Land disturbance

Home construction



Scientific Investigations Report 2004–5156

U.S. Department of the Interior
U.S. Geological Survey

Conversion Factors and Abbreviated Water-Quality Units

Multiply	By	To obtain
	Length	
inch (in)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	.4047	hectare (ha)
acre	.004047	square kilometer (km^2)
square ft (ft^2)	.09290	square meter (m^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
cubic foot (ft^3)	.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	.06309	liter per second (L/s)
inch per hour (in/h)	.0254	meter per hour (m/h)
	Mass	
pound, avoirdupois (lb)	.4536	kilogram (kg)
ton, short (2,000 lb)	.9072	megagram (Mg)
foot squared per day (ft^2/d)	.09290	meter squared per day (m^2/d)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Tables

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Hydrologic, Ecologic, and Geomorphic Responses of Brewery Creek to Construction of a Residential Subdivision, Dane County, Wisconsin, 1999–2002

By William R. Selbig, Peter L. Jopke[1], David W. Marshall[2], and Michael J. Sorge[2]

Abstract

The U.S. Geological Survey (USGS), in cooperation with the Dane County Land Conservation Department (LCD) and the Wisconsin Department of Natural Resources (DNR), investigated the instream effects from construction of a residential subdivision on Brewery Creek in Dane County, Wisconsin. The purpose of the investigation was to determine whether a variety of storm-runoff and erosion-control best-management practices (BMPs) would effectively control the overall sediment load, as well as minimize any hydrologic, ecologic, and geomorphic stresses to Brewery Creek.

Stormwater volumes decreased 60 percent from the preconstruction phase to the land-disturbance phase and slightly increased (9 percent) from the land-disturbance phase to the home-construction phase. The stormwater volumes were applied to total solids and total suspended solids concentrations to compute a solids load for each contaminant. Total and suspended solids load indicated a similar trend from preconstruction to land-disturbance phases with decreases of 52 and 72 percent, respectively. Both total and suspended solids load continued to decrease in the transition from land-disturbance to home-construction phases, by 22 and 37 percent, respectively. However, because of variability in the data, statistically there was no change in the magnitude of difference between the upstream and downstream solids load from one phase of construction to the next at the 90-percent confidence level.

Other physical, biological, and ecological surveys including macroinvertebrates, fish, habitat, and geomorphology were done on segments of Brewery Creek affected by the study area. Macroinvertebrate sampling results (Hilsenhoff Biotic Index value, or HBI), on Brewery Creek ranged from "very good" to "good" water-quality with no appreciable differences during any phase of construction activity. Results for fish-community composition, however, were within the "poor" range (Index of Biotic Integrity value, or IBI) during each year of testing. A general absence of intolerant species, with the exception of brown trout, reflects the low IBI values. Habitat values did not change significantly from preconstruction to postconstruction phases. Although installation of a double-celled culvert in Brewery Creek most likely altered the width-to-depth ratio in that reach, the overall habitat rating remained "fair". Fluvial geomorphology classifications including channel cross sections, bed- and bank-erosion surveys, and pebble counts did not indicate that stream geomorphic characteristics were altered by home-construction activity in the study area. Increases in fine-grained sediment at various cross sections were attributed to instream erosion processes, such as bank slumping, rather than increases in sediment delivery from the nearby construction site.

Introduction

Controlling nonpoint sources of water contamination has been a major focus of the regulatory community in recent years. Because of the past and current successes in controlling contamination from point sources, contamination from nonpoint sources (including sediment deposition, erosion, contaminated runoff, hydrologic modifications that degrade water quality, and other diffuse sources of contaminants) is now the largest cause of water-quality impairment in the United States (U.S. Environmental Protection Agency, 2001).

Conversion of rural and agricultural lands to developed urban areas is a leading contributor of nonpoint-source pollution. Urban development generates numerous contaminants that are associated with the activities of

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[2] Wisconsin Department of Natural Resources, Madison, Wisconsin

dense populations. Urban development also increases the amount of impervious surface in a watershed as farmland, forests, and meadowlands with generally high infiltration characteristics are converted into buildings with rooftops, driveways, sidewalks, roads, and parking lots with virtually no capacity to absorb stormwater. When stormwater and snowmelt runoff wash over these impervious areas, the runoff picks up contaminants along the way while gaining speed and volume, because it does not have the capacity to disperse and filter into the ground. The results are stormwater flows that are higher in volume, contaminant load, and temperature than the flows in less developed areas, which generally have more natural vegetation and soil to filter the runoff (U.S. Environmental Protection Agency, 1997).

Although water quality across the country has improved since passage of the Clean Water Act in 1972, various challenges still remain. In 2000, water-quality assessments conducted by States indicated that 39 percent of assessed stream miles, 45 percent of assessed acres of lakes, and 51 percent of assessed estuary areas failed to meet criteria for one or more designated uses. The top causes of impairment in assessed stream miles were siltation, nutrients, bacteria, metals (primarily mercury), and oxygen-depleting substances. Pollution from urban and agricultural land that is transported by precipitation and runoff was found to be the leading source of impairment (U.S. Environmental Protection Agency, 2002).

The U.S. Geological Survey (USGS), in cooperation with the Dane County Land Conservation Department (LCD) and the Wisconsin Department of Natural Resources (WDNR), investigated the instream water-quality effects from construction of a residential subdivision on Brewery Creek, Dane County, Wis. The purpose of the investigation was to determine whether storm-runoff and erosion-control best-management practices (BMPs) would effectively control the overall sediment load, as well as minimize any physical, biological, and ecological stresses to Brewery Creek.

Few previous studies have assessed the capacity of erosion and sediment controls and stormwater-management practices to prevent degradation of receiving waters in urbanizing areas. Even fewer studies have been multiparameter investigations, integrating water-quality observations with evaluations of stream physical habitat and biological quality. This investigation paired water-quality analyses with physical habitat, stream geomorphology, and biological indices to evaluate the capacity of selected management techniques to prevent degradation of a receiving stream.

This study has relevance at both national and local levels. At the national level, the investigation could provide necessary background data on water-quality impairments related to construction-site runoff. This, in turn, would help facilitate the implementation of Phase II of the USEPA National Pollution Discharge Elimination System (NPDES) standard for pollution control on construction sites of less than 5 acres. At the local level, county officials are mandating construction-site erosion-control standards throughout Dane County. The objective of this investigation was to provide evidence of the effects that construction has on hydrology, ecology, and morphology of receiving waters.

Purpose and Scope

This report describes the methods used in and the results from the Brewery Creek study. An upstream-downstream (above-and-below) experimental design was used to isolate the pollutant loads coming from the construction site. Automated, intensive stream-water sampling took place during storm-runoff periods in three different phases on the project: preconstruction (October 1999 to April 2001), land disturbance (May 2001 to March 2002), and home construction (April 2002 to September 2002). Concentrations of total solids and total suspended solids in stream-water samples were used to compute storm loads for each contaminant contributed to Brewery Creek during each phase. In addition to water quality and quantity, other physical and biological data were analyzed to determine the effectiveness of storm-runoff and erosion controls in protecting the integrity of Brewery Creek. Geomorphology classifications, including bed- and bank-material characterizations, were done at intervals throughout the study period. Stream temperatures were recorded at 15-minute intervals during each phase of the project. Annual fish surveys were done to determine species composition and density. Finally, macroinvertebrate and habitat data were collected at various intervals to assess the overall health of the stream.

Description of Study Area

Brewery Creek is in the Black Earth Creek watershed, in northwestern Dane County (fig. 1). The drainage area of 10.5 mi^2 at the downstream end of the study area includes 2.8 mi^2 of noncontributing area. The stream is 6.1 mi long from the downstream station to the stream headwaters; 0.5 mi is within the study area. The stream has been

Figure 1. Location of the Brewery Creek Watershed within the Black Earth Creek Watershed in Dane County, Wis.

channelized in places, with the upper reaches of the stream last being dredged in 1976. The stream bed material is mostly soft silt and clay. Brewery Creek flows through outwash and alluvium composed of sandstone with some shale; most of the bedrock in the watershed is dolomite (Graczyk and others, 2003). The soils of Brewery Creek Watershed are predominantly silt loams that are poorly drained in valley bottoms and highly erodible in the uplands (Glocker and Patzer, 1978). Brewery Creek is a warm-water stream that maintains a forage fish population (Wisconsin Department of Natural Resources, 1989). Although classified as a warm-water stream, the stream does support cold-water species and is a candidate to be reclassified as a cold-water stream by the WDNR (Wisconsin Department of Natural Resources, 1989). The largest land-use categories in the Brewery Creek Watershed are agriculture, at 57 percent, and woodland, at 22 percent (Graczyk and others, 2003).

The St. Francis residential subdivision includes single-family lot development over approximately 72 acres. It lies in the southernmost part of the Brewery Creek Watershed and represents approximately 4 percent of the basin area (fig. 2). The area had previously been used for corn and soybean production. An established vegetated stream buffer varies from 30 to 100 ft in width on either side of the stream.

Erosion Control and Stormwater Management at the Subdivision Site

Since August 22, 2002, all municipalities in Dane County, Wisconsin have been required to meet the requirements of the Dane County Erosion Control and Stormwater Management Ordinance. In Dane County, all developments disturbing more than 4,000 ft^2 are required to implement an erosion-control plan. Stormwater-management plans are required when 20,000 ft^2 or more of impervious surface is created. (Chapter 14, Dane County Code of Ordinances). During the general permitting of the St. Francis subdivision, these regulations were not applicable because the permit was issued in April 2001. However, the developer agreed to design and implement an erosion-control and stormwater-management plan that would meet or exceed requirements in the proposed Dane County Ordinance.

The St. Francis subdivision employed a variety of BMPs constructed for erosion control and stormwater management. The erosion-control practices were designed to meet the maximum allowable cumulative soil loss of 7.5 ton/acre/yr. Practices included installing silt fence reinforced with straw bales, maintaining vegetative buffers (fig. 3), sequencing construction, deep tilling to minimize compaction, temporary seeding of soil stockpiles, protecting inlets, emplacing stone tracking pads, and building temporary earthen berms.

Stormwater-management practices were designed and implemented in accordance with the water-quality and -quantity standards under development in the Dane County Erosion Control and Stormwater Management Ordinance. The applicable standards included the following:

- Maintaining the predevelopment peak-runoff rates for the 2-year and 10-year, 24-hour storms, and safely passing the 100-year flood.
- Discharging to a stable outlet carrying the designed flows at a nonerosive velocity.
- Retaining all soil particles greater than 5 microns.
- Directing runoff from downspouts, driveways, and other impervious areas to pervious areas.
- Including provisions and practices to reduce the temperature of runoff to the receiving waters.

Stormwater-management practices included grassed swales and boulevards for infiltration and storage of runoff, reduced street widths to minimize impervious cover, protection of present woodlands, two detention and infiltration basins with stone cribs for thermal protection, maintenance of stream buffers, and use of available parkland and open space for runoff storage and infiltration. Figure 4 highlights some of the BMPs used in the development of the study area.

The site was designed to maximize infiltration of runoff on the basis of predevelopment soil and permeability rates. Surface runoff is diverted from impervious surfaces to one or more BMPs for temporary storage and infiltration. Runoff first enters grassed swales in the street medians (fig. 4). The swales were designed to infiltrate stormwater over a period of 24 hours. During periods of intense runoff, excess water in the swale enters a conveyance system that directs runoff to a larger infiltration basin, where it is temporarily stored and allowed to infiltrate. Each system is designed to reduce water quantity and improve water quality before runoff enters Brewery Creek. Vegetated buffers were left intact during site grading and plot construction to provide additional water-quality benefit.

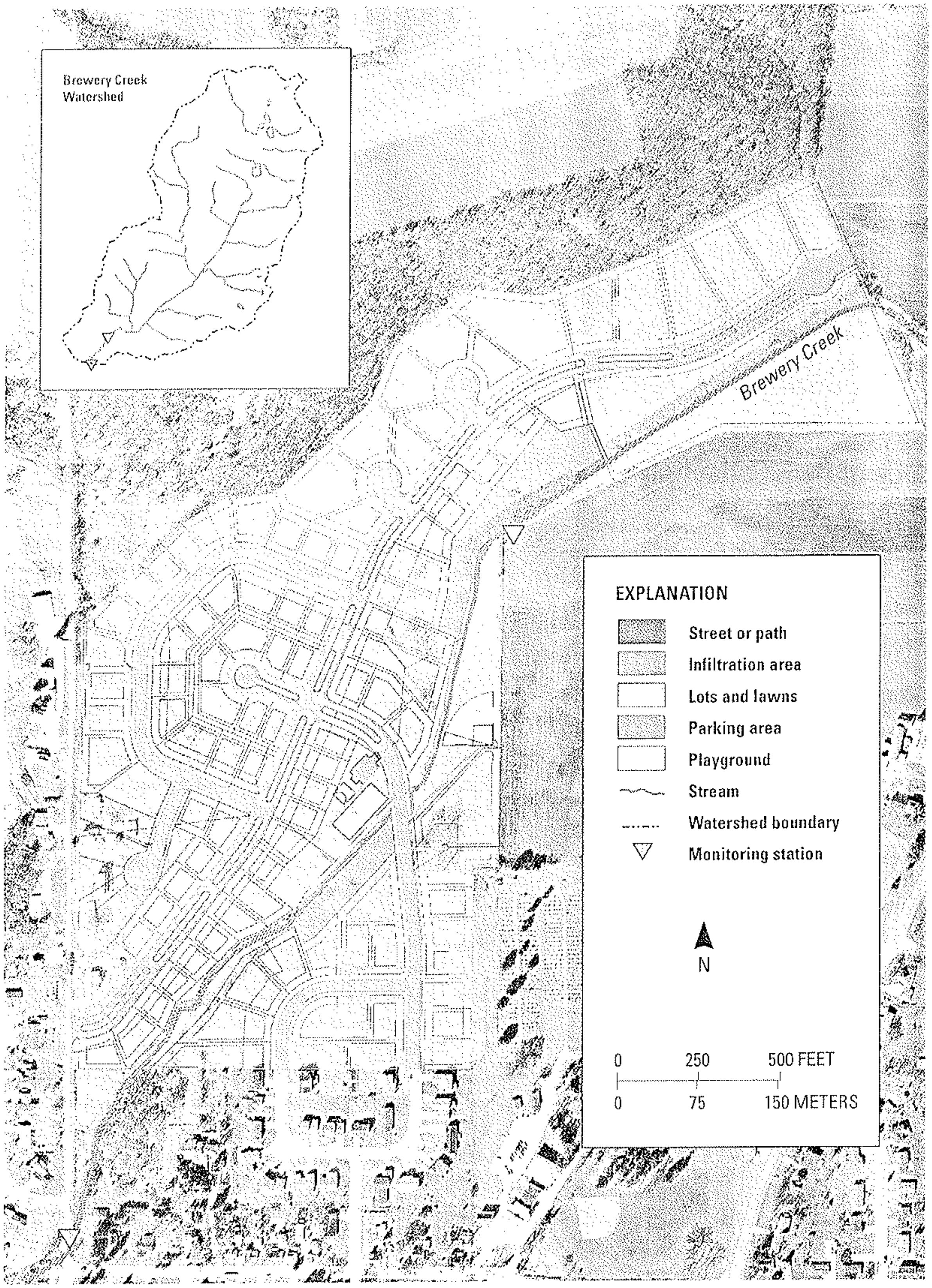

Figure 2. Location of the St. Francis residential subdivision in the Brewery Creek Watershed, Dane County, Wis.

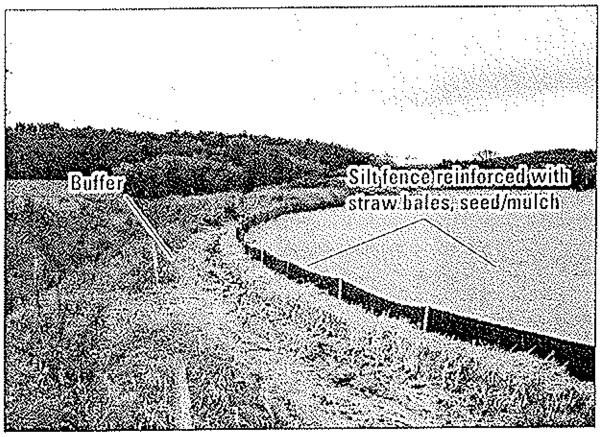

Figure 3. Example of erosion-control practices at the St. Francis residential subdivision, Dane County, Wis. (View looking upstream).

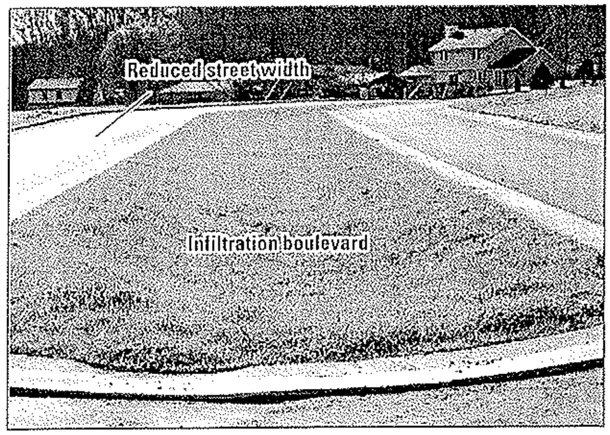

Figure 4. Example of stormwater-management practices at the St. Francis residential subdivision, Dane County, Wis.

Methods of Data Collection

Data collection in the study area involved water-quantity and sediment measurement at two monitoring stations and habitat, biologic, and geomorphic data near each station. Locations of the data-collection stations are shown in figure 5.

Water-Quantity, Precipitation, and Water-Quality Measurement

A stream-monitoring station had been established at the downstream site in 1984 and was active from 1984 to 1986; 1989 to 1998, and May 1999 to September 2002. The upstream monitoring station was established in October 1999. The location of each station in relation to the study area is shown in figure 5. Although the upstream station appears to be near the center of the study area, all construction activity was confined to the area between the upstream and downstream stations for the duration of the study. Future development has been planned beyond the upstream station. Each station continuously measured stream levels and water temperature, and event-based water samples also were collected. Water-level measurements were recorded in 15-minute increments during periods of base flow and 5-minute increments during storm events.

A storm event was defined as a period of precipitation bracketed by 6 hours or more of no precipitation. In some cases, storm events were defined as a period of precipitation bracketed by 12 hours or more of no precipitation; these events typically were the result of stormwater runoff continuing beyond a 6-hour period of no precipitation, followed by a second burst of rainfall causing additional runoff.

Water Quantity. Changes in stream levels were measured with a bubble-gage system and pressure transducer. Stream levels were then converted to a discharge rate by use of a field-verified rating table. A V-notch weir was added to the upstream station to gain added sensitivity of measured discharge for small fluctuations in water level, whereas the downstream channel cross section provided sufficient accuracy.

Precipitation. Precipitation was measured at the downstream station with a tipping-bucket raingage. Because of the close proximity to the upstream station, all precipitation data were collected at a single station. Precipitation depths, intensities, and erosivity indices were computed for all storm events except snowmelt. See tables A1 through A3 in the appendix for precipitation data. Intensities are reported in 5-, 10-, 15-, 30-, and 60-minute increments.

Water Quality. Stream temperature was measured with a Teflon-shielded thermocouple at a single point in the water column at each stream-monitoring station.

Automated water samplers at each station collected samples for water-quality analyses. Sample collection was activated by a rise in stream level during a storm event. Once a stream-level threshold was exceeded, typically a rise of 0.10 ft above base-flow level, the volume of water passing the station was measured and accumulated at 1-minute increments until a volumetric threshold was reached. At that point, the sampler collected a discrete water sample and the volumetric counter was reset. The process was repeated until the stream level receded below the threshold.

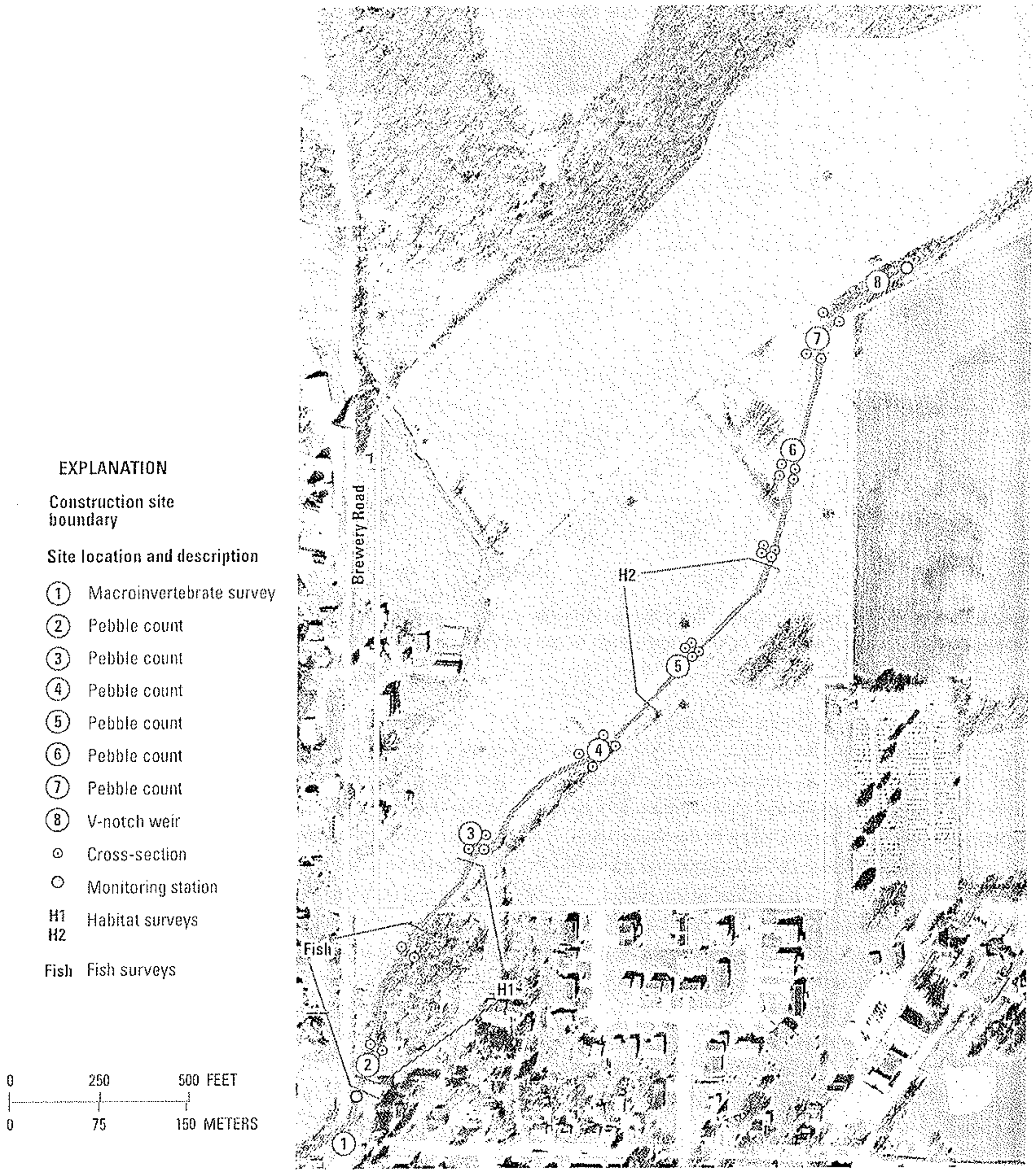

Figure 5. Locations of habitat, biologic, and geomorphic data acquisition on Brewery Creek, Cross Plains, Wis.

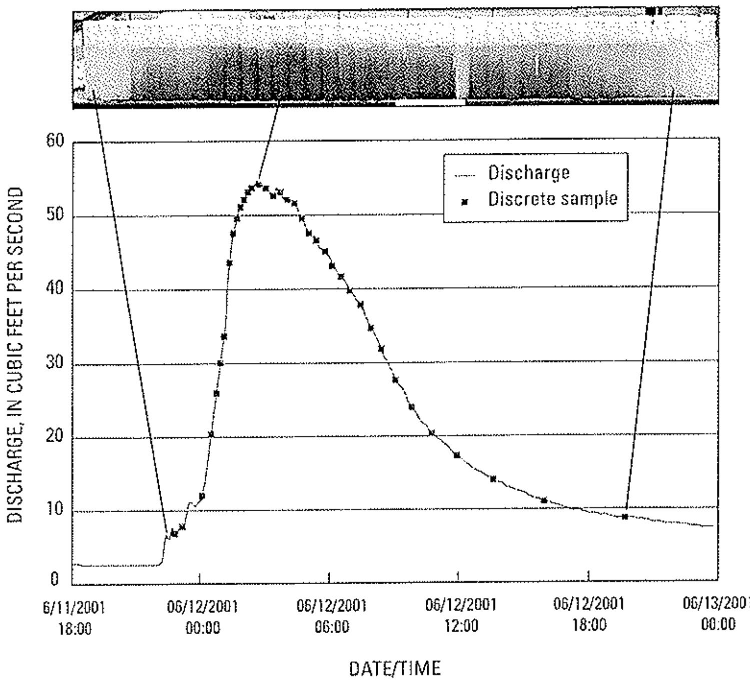

Figure 6. Discrete samples collected during a single storm event on Brewery Creek, Cross Plains, Wis. Note how samples change in color (change in sediment concentration) with respect to the rising and receding limb of the hydrograph.

These flow-weighted samples were collected and composited into a single water sample, then split and processed for analysis. A Teflon-coated, stainless-steel churn splitter was used to composite and split samples. Processed samples were placed on ice and taken to the Wisconsin State Laboratory of Hygiene (WSLH) within 48 hours after runoff cessation for determination of concentrations of total and suspended solids. Because each discrete sample was composited into a single event sample, the resulting concentration represents the event mean concentration (EMC). In some cases, individual discrete samples were submitted to the laboratory to gain a better understanding of concentration variations during a storm event. Figure 6 illustrates how discrete samples were acquired over a single storm event.

Solids loads were computed by multiplying the EMC by the total volume of the storm event and a constant for unit conversion. For those events in which discrete-sample concentrations were used rather than an EMC, continuous streamflow and instantaneous concentration data were used to estimate loads of total and suspended solids. In this case, loads were computed by summing the product of streamwater-sample concentration and streamflow rate for that storm-runoff period (Porterfield, 1972).

To ensure sample integrity, field and sample-processing equipment blanks were collected at the upstream and downstream stations. Blank samples were obtained by drawing deionized water through the suction line and sampler into a collection bottle. The Teflon sample line and automatic sampler were not cleaned before obtaining blank samples. Blank water collected in the sample bottle was then run through the Teflon-lined churn splitter into laboratory-prepared sample bottles. Samples were placed on ice and delivered to the WSLH for analysis. Deionized blank water was also used to isolate individual elements of the sampling process from source to delivery. These samples were not delivered to the WSLH unless erroneous concentrations were found in the original blank sample. Blank-sample results are detailed in table A4 in the appendix. A significant concentration of total and suspended solids was detected in the upstream blank sample collected in August 1999. This blank sample may have been compromised by stream water entering the sample tubing while the blank sample was being acquired. An additional blank sample was acquired as an added quality measure. The results of that sample fell within acceptable limits.

Sample-collection bottles were cleaned with a nonphosphate detergent, tapwater rinse, and hydrochloric acid rinse and then were air-dried. Clean bottles replaced soiled bottles upon collection of the samples and remained in the sampler housing until the next runoff event. A Teflon-lined churn splitter was rinsed with deionized water before sample processing.

Replicate samples were submitted to verify reproducibility with automatically collected samples. Replicate samples were checked for precision on the basis of a relative percent difference (RPD). Manual samples were collected periodically to verify reproducibility with corresponding stream equal-width-increment (EWI) samples (Ward and Harr, 1990). Manual samples were also checked for precision on the basis of a relative percent difference. Total and suspended solids RPD values fell below the 20-percent-precision criteria for both upstream and downstream replicate samples. However, RPD values exceeded the 20-percent criteria on suspended solids at the upstream station and downstream station in August 2002. Replicate and manual sample results are listed in table A4 in the appendix.

Macroinvertebrate- and Fish-Community Assessment

Macroinvertebrate communities were sampled in the spring and (or) fall beginning in October 1999. A D-frame net was used to sample riffle habitats in Brewery Creek at Brewery Road (fig. 5). An additional site located on Brewery Creek at Highway 14 (fig. 7) was also sampled because of its extensive historical macroinvertebrate data record for comparison. Samples were submitted to the Biomonitoring Laboratory at the University of Wisconsin at Stevens Point for processing and identification. The semi-quantitative methodology used in the study for sampling and biotic index calculation was the Hilsenhoff Biotic Index, or HBI (Hilsenhoff, 1987), which is based on sensitivity of various aquatic insects and crustaceans to organic contamination. The HBI water-quality scale ranges from 0 to 10, with 0 indicating best possible water quality and 10 the worst.

Fish communities were sampled at least once per year beginning in October 1999. A towed barge with two electrodes was used to sample 160 m of stream above Brewery Road (fig. 5). The sampling methodology and Coldwater Index of Biotic Integrity, or IBI, calculation used for assessing the environmental health of trout streams was developed by Lyons and others (1996). The Coldwater IBI is based on variable tolerances of different fish species to environmental degradation. Scores range from 0 (worst) to 100 (best). The presence of numerous trout, intolerant species, and numerous species adapted to cold temperatures score the highest and indicate favorable stream conditions.

Habitat Assessment

Physical characteristics of the stream at both sites were measured to document present conditions. Measurements included stream width, stream depth, depth of fines, bank erosion, substrate type and amount, and cover for fish; all were recorded at 48 transects at each "habitat station" (H1 and H2), a stream reach whose length is 36 times the mean stream width (fig. 5).

Surveys also were done during summer 2003 to determine whether construction had an effect on fish habitat. The surveys followed methods outlined in "Guidelines For Evaluating Fish Habitat in Wisconsin Streams," (Simonson and others, 1994). Qualitative ratings have been established to characterize the physical habitat available for fish. The habitat scores range from 0 to 100, with 0 indicating the worst habitat for fish and 100 being optimal.

Geomorphic Assessment

The segment of Brewery Creek investigated for this study included both straightened channel and natural channel (pools, riffles, and runs). The upper reaches of the creek have been hydraulically manipulated by past dredging for agricultural purposes.

Various methods were used to determine physical stream characteristics and any subsequent changes resulting from construction activity. Stream classifications, channel cross sections, pebble counts, and bed- and bank-erosion surveys were done according to methods outlined in "Stream Channel Reference Sites: An Illustrated Guide to Field Technique" (Harrelson and others, 1994). Stream classifications were done in 2001 and 2003, whereas channel cross sections and bed- and bank-erosion surveys were completed during 2001 to 2003.

Fourteen cross sections were established with permanent monuments placed in representative locations (fig. 5). Monuments consisted of 4-ft sections of rebar anchored into the ground with 4-in diameter pvc tubes filled with concrete (fig. 8). Annual surveys were conducted by use of a surveyor's level. Survey points included monuments, top of bank, bankfull, bank pins, and water levels.

Bank Pins. Bank pins consisting of 4-ft sections of 3/8-in. rebar were inserted horizontally into the streambank at most permanent cross sections at or slightly above bankfull in fall 2001. Bank pins were set flush with the bank and were intended to measure subtle changes in erosion and deposition to the banks. Measurements of the amount of material either deposited or the amounts of the bank pin exposed (erosion), in millimeters were made in

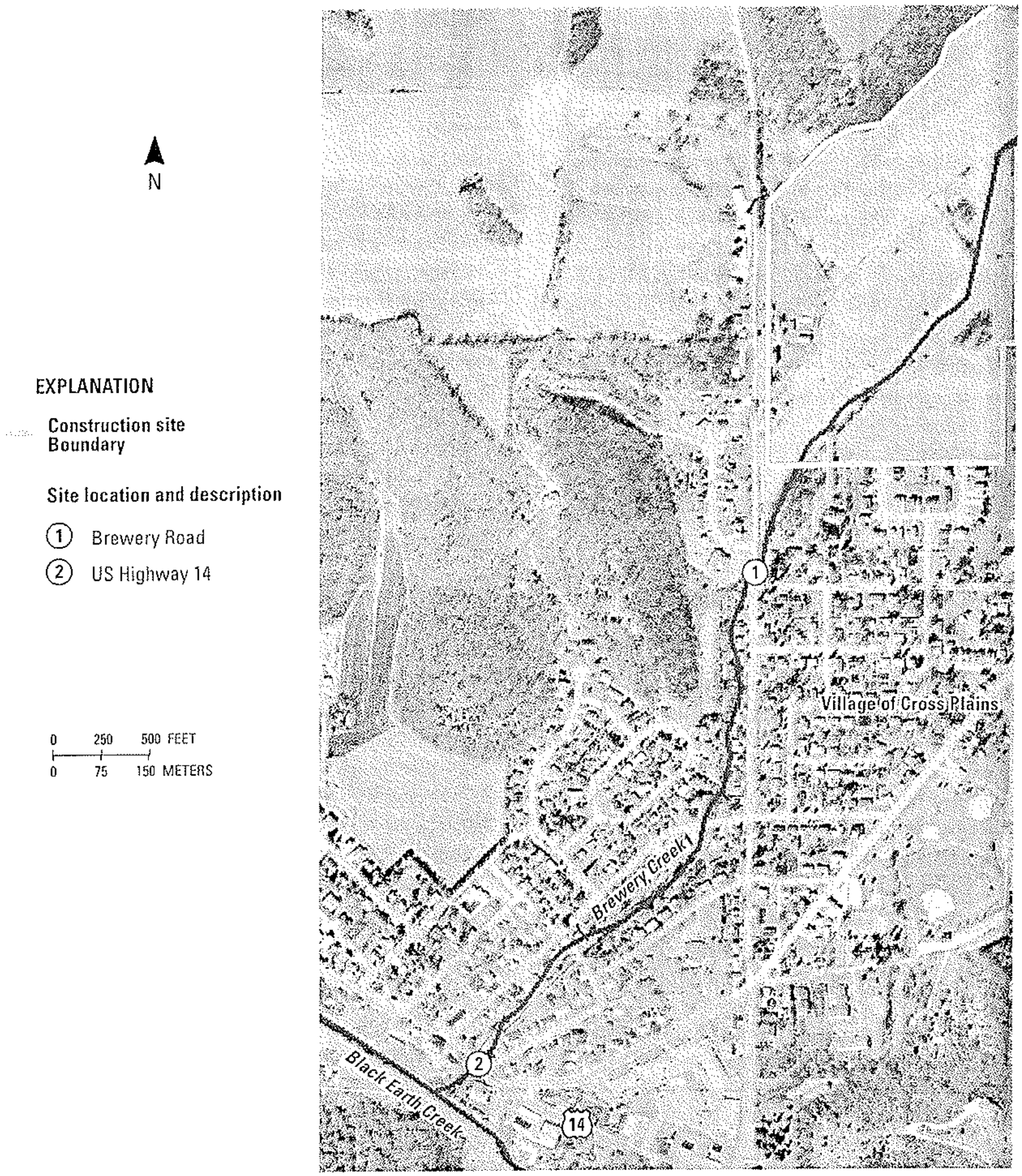

Figure 7. Locations of macroinvertebrate surveys on Brewery Creek, Cross Plains, Wis.

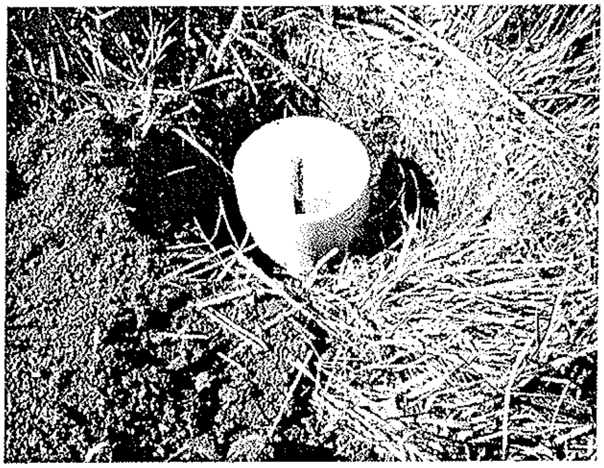

Figure 8. Example of permanent monument used in geomorphic assessment to mark cross sections along Brewery Creek, Cross Plains, Wis.

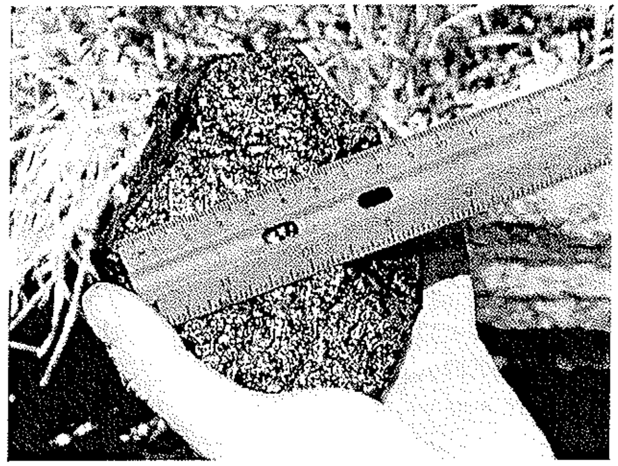

Figure 9. Measuring a streambed rock along the intermediate axis as part of a Wolman Pebble Count in Brewery Creek, Cross Plains, Wis.

September 2002 and October 2003 and noted differences as either deposition or erosion. If possible, pins were reset to "0" or flush with the bank. Because of severe slumping, this was not possible in most locations. Data were recorded and used for comparison at all cross sections where bank pins were installed.

Stream Classification. Two segments of Brewery Creek were classified using Rosgen's Stream Classification System (Rosgen, 1996). Cross-sections 1 (the furthest upstream site in the channelized reach) and 9 (meandering reach) were classified in October 2001 and repeated in October 2003 to compare different reaches of stream. Stream variables used in the classification procedure include slope, sinuosity, width/depth ratio, entrenchment ratio, and dominant bed material.

Wolman Pebble Count. The Wolman Pebble Count Procedure was used to characterize the composition of the streambed at seven locations. Pebble counts were done in 2001, 2002, and 2003. Selected reaches were sampled (step-toe procedure) from bankfull to bankfull in a random fashion. A minimum of 100 samples were recorded per location. Particles were tallied according to the Wentworth size classes. Particles larger than sand (greater than 2 mm) were measured along the intermediate axis (fig. 9) and recorded under the appropriate size class. Data were plotted annually by size class and frequency.

Hydrologic Response

Data on runoff volume, solids load, and EMC for each storm event are listed in tables 1 and 2; a statistical summary of runoff volume and solids results for each phase of the study is given in table 3. Temperature data are listed in table 4.

Large differences in rainfall patterns between each phase could potentially bias the results of data analyses. To determine whether each construction phase differed with respect to rainfall depth and intensity (in the form of an erosivity index), the Kruskal-Wallis test was used. Precipitation depth and intensities indicated a nonnormal distribution. The Kruskal-Wallis test checks for a difference between the medians of independent samples for nonnormal datasets. No significant differences between the preconstruction and land-disturbance phases were detected at the 90-percent confidence level. Similarly, no significant differences were detected between the land-disturbance and home-construction phases. Therefore, any differences between the downstream and upstream stations between study phases are not likely because of differences in rainfall patterns.

On the whole, the downstream-upstream experimental design worked well at documenting the effects of the BMP systems from preconstruction through the home-construction phases. This design could continue to have merit in documenting further changes in water volume, solids load, and stream temperature after the residential development is completely built out.

Solids Load

Critical to obtaining useful conclusions for this study was the ability to document that downstream loads were significantly greater than upstream loads before any BMPs

Table 1. Description of runoff events at the upstream water-quality sampling station in Brewery Creek, Cross Plains, Wis.

[** - Discrete samples only; mg/L, milligrams per liter]

Brewery Creek upstream							
Sampled runoff event		Storm information		Average solids loads		Event mean concentration (EMC)	
Start date	Construction phase	Precip. depth (inches)	Runoff volume (cubic feet)	Total solids (tons)	Suspended solids (tons)	Total solids (mg/L)	Suspended solids (mg/L)
02/22/00	Preconstruction	snowmelt	3,574,500	72.5	36.9	650**	331**
04/19/00	Preconstruction	2.13	1,531,300	27.5	6.6	576**	138**
05/17/00	Preconstruction	5.04	6,116,800	307.4	263.5	1,610	1,380
05/30/00	Preconstruction	5.07	17,508,000	1,032.9	890.8	1,890	1,630
06/04/00	Preconstruction	.88	807,500	13.8	3.9	548	156
06/13/00	Preconstruction	2.70	4,491,300	171.0	136.0	1,220	970
07/02/00	Preconstruction	.99	661,900	19.8	13.7	960	664
07/10/00	Preconstruction	.73	322,200	4.4	.8	438	75
08/05/00	Preconstruction	1.81	422,100	5.8	.7	438	56
08/17/00	Preconstruction	.96	268,900	4.2	.2	496	17.5
09/11/00	Preconstruction	1.08	625,000	9.4	1.1	484	54
09/22/00	Preconstruction	.64	507,900	7.9	.6	496	35
04/11/01	Preconstruction	.73	392,100	7.5	2.9	546	136
05/10/01	Land-disturbance	.75	152,900	2.5	.7	596	157
05/21/01	Land-disturbance	2.02	1,334,800	29.2	14.8	662	298
05/23/01	Land-disturbance	.54	368,100	6.2	.9	518	68
06/05/01	Land-disturbance	.73	268,700	4.6	1.4	534	101
06/11/01	Land-disturbance	2.07	1,937,800	57.1	38.7	944	640
08/01/01	Land-disturbance	9.56	22,855,400	694.4	570.2	974**	800**
08/22/01	Land-disturbance	.20	119,300	1.9	.1	502	36
08/25/01	Land-disturbance	1.31	365,400	5.5	.9	494	57
09/17/01	Land-disturbance	.57	321,800	5.2	.5	522	48
09/19/01	Land-disturbance	1.06	662,900	10.0	3.1	498	114
09/23/01	Land-disturbance	1.73	1,424,500	27.0	15.5	584	262
10/22/01	Land-disturbance	1.17	462,700	7.6	1.7	520	90
11/24/01	Land-disturbance	.82	342,000	6.7	1.9	574	119
12/12/01	Land-disturbance	.58	291,900	5.9	1.9	586	141
02/18/02	Land-disturbance	1.68	1,878,600	37.0	14.3	600	199
03/08/02	Land-disturbance	.45	1,066,200	20.2	7.5	592	206
04/07/02	Home-construction	1.35	1,057,500	18.4	5.1	558	154
04/18/02	Home-construction	.66	220,400	4.1	1.1	602	153
04/24/02	Home-construction	.39	177,300	2.9	.6	530	103
04/27/02	Home-construction	.70	556,900	9.3	1.3	534	74
05/01/02	Home-construction	.56	271,600	4.5	.8	526	92
05/09/02	Home-construction	.78	461,800	11.5	6.4	796	442
05/11/02	Home-construction	.83	637,600	14.6	7.8	696	337
05/28/02	Home-construction	.30	134,000	2.2	.3	522	75
06/03/02	Home-construction	.24	517,400	23.1	18.7	1,430	1,160
06/04/02	Home-construction	.36	1,206,600	22.6	8.6	600	228
07/22/02	Home-construction	1.16	251,000	3.90	.4	498	47
08/11/02	Home-construction	1.74	431,300	6.1	1.5	460	94
08/21/02	Home-construction	.93	479,700	7.7	.6	516	38
09/02/02	Home-construction	1.05	312,400	5.3	.7	540	67

Table 2. Description of runoff events at the downstream water-quality sampling station in Brewery Creek, Cross Plains, Wis.

[** - Discrete samples only; mg/L, milligrams per liter]

Brewery Creek downstream							
Sampled runoff event		Storm information		Average solids loads		Event mean concentration (EMC)	
Start date	Construction phase	Precip. depth (inches)	Runoff volume (cubic feet)	Total solids (tons)	Suspended solids (tons)	Total solids (mg/L)	Suspended solids (mg/L)
02/22/00	Preconstruction	snowmelt	3,862,800	87.0	50.5	722**	419**
04/19/00	Preconstruction	2.13	1,755,700	32.1	8.6	586**	157**
05/17/00	Preconstruction	5.04	7,077,700	291.6	229.8	1,320	1,040
05/30/00	Preconstruction	5.07	18,098,100	1,050.8	909.5	1,860	1,610
06/04/00	Preconstruction	.88	908,000	13.0	1.4	458	48
06/13/00	Preconstruction	2.70	4,838,800	179.7	149.5	1,190	990
07/02/00	Preconstruction	.99	662,600	20.7	15.2	1,000	736
07/10/00	Preconstruction	.73	343,200	5.1	.7	476	62
08/05/00	Preconstruction	1.81	521,300	8.0	2.1	490	130
08/17/00	Preconstruction	.96	308,800	4.7	.2	486	24
09/11/00	Preconstruction	1.08	766,900	11.9	2.0	498	82
09/22/00	Preconstruction	.64	580,600	9.2	.8	506	42
04/11/01	Preconstruction	.73	451,000	9.4	4.0	614	218
05/10/01	Land-disturbance	.75	150,400	1.9	.6	624	205
05/21/01	Land-disturbance	2.02	1,383,500	37.3	22.5	864	522
05/23/01	Land-disturbance	.54	415,800	6.6	1.1	512	84
06/05/01	Land-disturbance	.73	329,100	6.1	1.8	566	124
06/11/01	Land-disturbance	2.07	2,104,700	96.6	80.8	1,470	1,230
08/01/01	Land-disturbance	9.56	24,816,900	930.2	802.0	1,202**	1,036**
08/22/01	Land-disturbance	.20	147,300	1.8	.2	488	49
08/25/01	Land-disturbance	1.31	352,700	5.8	1.4	518	94
09/17/01	Land-disturbance	.57	342,400	5.7	.5	534	49
09/19/01	Land-disturbance	1.06	696,400	11.4	2.8	522	117
09/23/01	Land-disturbance	1.73	1,535,200	33.7	20.3	654	325
10/22/01	Land-disturbance	1.17	558,200	9.5	2.8	526	110
11/24/01	Land-disturbance	.82	341,600	6.4	1.7	576	136
12/12/01	Land-disturbance	.58	273,300	4.9	1.3	536	102
02/18/02	Land-disturbance	1.68	1,943,400	40.8	17.5	632	234
03/08/02	Land-disturbance	.45	1,070,500	19.9	6.8	582	188
04/07/02	Home-construction	1.35	1,096,300	18.3	4.2	536	123
04/18/02	Home-construction	.66	240,300	4.2	1.1	562	144
04/24/02	Home-construction	.39	189,200	3.0	.5	506	79
04/27/02	Home-construction	.70	568,300	8.8	1.0	496	57
05/01/02	Home-construction	.56	292,800	4.4	.6	484	70
05/09/02	Home-construction	.78	511,800	11.7	6.5	734	409
05/11/02	Home-construction	.83	727,500	16.7	8.9	688	332
05/28/02	Home-construction	.30	152,700	2.4	.4	512	76
06/03/02	Home-construction	.24	571,800	24.5	20.2	1,370	1,130
06/04/02	Home-construction	.36	1,398,600	25.9	11.0	594	251
07/22/02	Home-construction	1.16	281,800	4.4	.8	498	96
08/11/02	Home-construction	1.74	525,500	7.3	2.6	452	127
08/21/02	Home-construction	.93	558,000	8.6	.7	494	42
09/02/02	Home-construction	1.05	380,000	5.9	.7	490	50

Table 3. Statistics for measured storm events at the upstream and downstream water-quality gages, Brewery Creek, Cross Plains, Wis.

Statistic	Construction phase: Pre-construction	Land-disturbance	Home-construction
DOWNSTREAM SITE			
Volume (cubic feet x 106)			
Mean	3.09	2.28	.54
Median	.77	.49	.52
Maximum	18.10	24.82	1.40
Minimum	.31	.15	.15
Coeff. of variation	1.61	2.65	.66
Total solids (tons)			
Mean	132.5	76.2	10.4
Median	13	8	8
Maximum	1050.75	930.2	25.93
Minimum	4.69	1.81	2.44
Coeff. of variation	2.18	3.01	.75
Suspended solids (tons)			
Mean	105.71	60.25	4.22
Median	3.95	2.26	1.05
Maximum	909.52	802	20.17
Minimum	.23	.18	.36
Coeff. of variation	2.38	3.3	1.36
UPSTREAM SITE			
Volume (cubic feet x 106)			
Mean	2.86	2.12	.48
Median	.66	.42	.45
Maximum	17.51	22.86	1.21
Minimum	.27	.12	.13
Coeff. of variation	1.67	2.63	.66
Total solids (tons)			
Mean	129.54	57.57	9.73
Median	13.81	7.16	6.91
Maximum	1032.88	694.4	23.09
Minimum	4.16	1.87	2.18
Coeff. of variation	2.21	2.96	.74
Suspended solids (tons)			
Mean	104.43	42.12	3.83
Median	3.93	1.9	1.17
Maximum	890.79	570.2	18.73
Minimum	.15	.13	.31
Coeff. of variation	2.38	3.35	1.36

were in place. Results from the Wilcoxon signed ranks test, used to find differences between paired data sets, revealed that downstream loads were significantly greater than upstream loads at the 90-percent confidence level. Therefore, the study area was an important contributor of total and suspended solids to Brewery Creek. However, previous studies indicate that streambank slumping could be an additional input to the solids load of the stream in addition to inputs related to construction activities (Allen and Gray, 1984).

Summary statistics for solids load at the downstream and upstream gages during each phase of the study are listed in table 3. Mean volume, total solids load, and total suspended solids load are greater at the downstream site than the upstream site for each phase of construction. However, examination of downstream and upstream volumes and loads revealed a highly skewed distribution. Large rain events can skew the distribution of volume and solids load. One such event occurred in August 2001 when over 9.5 in of rain was recorded at the downstream station within 48 hours. This type of event is atypical and should be given less weight statistically. Median rather than mean values were used during statistical analyses because the median is a more appropriate representation of the population center in highly skewed data sets than the mean. (Ott and Longnecker, 2001).

The difference between downstream and upstream loads was computed for total and suspended solids for the preconstruction, land-disturbance, and home-construction phases. Changes in the magnitude of the differences are believed to be a result of activity in the study area. The erosion-control and stormwater BMPs used at the construction site were effective at limiting the amount of solids load entering Brewery Creek (fig. 10). Each bar represents the median of all differences between the downstream and upstream constituent loads for the preconstruction, land-disturbance, and home-construction storm-runoff periods. Differences in median total solids loads decreased by 52 percent between the preconstruction and land-disturbance phases and 22 percent between the land-disturbance and home-construction phases (fig. 10). Similarly, downstream-upstream differences in suspended-solids loads decreased 72 and 37 percent, respectively (fig. 10).

However, examination of the median value fails to explain the variability of the data. Most of the coefficients of variation in table 3 have a value greater than 1, indicating substantial variability in solids load. The Wilcoxon rank sum test (Ott and Longnecker, 2001) was used to describe the variability of the data and to ultimately

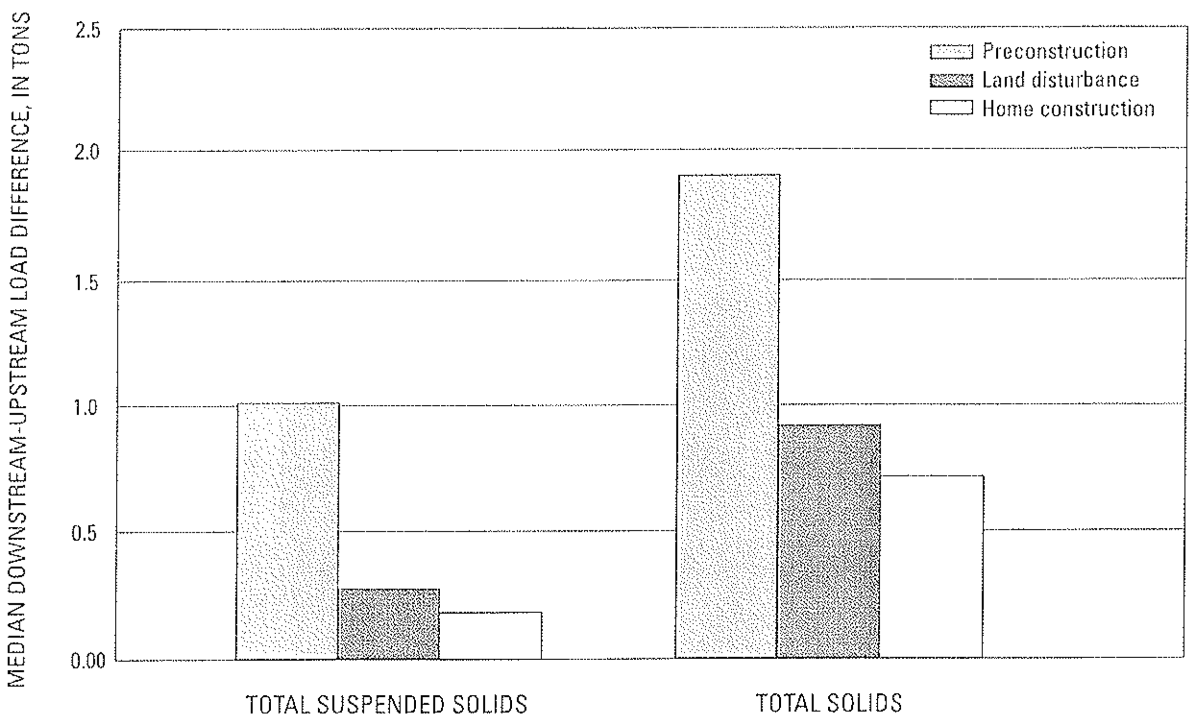

Figure 10. Median value of difference between downstream and upstream total solids and total suspended solids load in Brewery Creek during each phase of construction activity at the St. Francis residential subdivision, Cross Plains, Wis.

determine whether the contribution of loads significantly increased or decreased from one phase of construction to the next. The null hypothesis states there is no change in the magnitude of the difference between the upstream and downstream solids load from one phase of construction to the next. The alternative hypothesis suggests there is a significant change in the magnitude of the difference between the downstream and upstream solids load from one phase of construction to the next and this change is related to BMP effectiveness. Results from the test, at the 90-percent confidence level, failed to reject the null hypothesis. The data provide insufficient evidence to report an increase or decrease in solids load from preconstruction levels. Because the test did not indicate a significant increase in solids load, one could imply the BMP systems implemented before and during the land-disturbance and home-construction phases are at least somewhat effective at limiting the amount of solids entrained in runoff from reaching Brewery Creek. This limitation is supported by the reduction in the magnitude of differences between downstream and upstream total solids and total suspended solids load from one phase of construction to the next (fig. 10).

Runoff Volume

Summary statistics for event volumes are also detailed in table 3. Similar to solids loads, the median of all differences between the upstream and downstream volumes were determined for each phase of the study. A 60-percent reduction in median runoff volumes from the preconstruction to the land-disturbance phase is illustrated in figure 11; results from the Wilcoxon rank sum test shows this difference to be significant at the 90-percent confidence level.

Median runoff volumes appeared to increase slightly between the land-disturbance to the home-construction phases (fig. 11); however, statistical tests indicated no significant difference in runoff volume between these two phases. The apparent increase could be due, in part, to the failure of a runoff infiltration pond during the home-construction phase. Overall, the BMPs utilized within the study area were able to reduce the amount of stormwater runoff entering Brewery Creek.

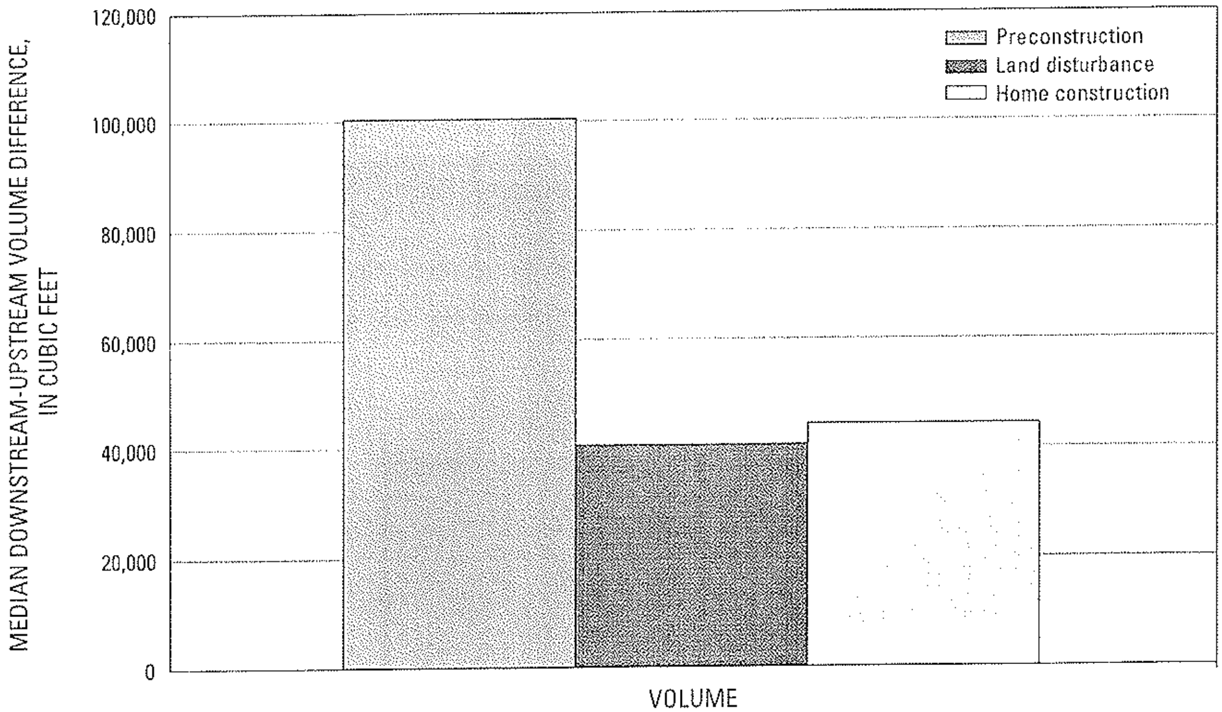

Figure 11. Median value of difference between downstream and upstream event volume in Brewery Creek during each phase of construction activity at the St. Francis residential subdivision, Cross Plains, Wis.

Stream Temperature

The temperature of urban streams is often affected directly by urban runoff. For example, Galli (1990) demonstrated an increase in base flow water temperature of 0.14°C for every 1-percent increase in watershed imperviousness. Although the Brewery Creek Watershed contains only 3 percent urban land, the stream flows through an urban environment for approximately 0.5 mi before its confluence with Black Earth Creek, a Class I trout stream. Certain species of fish, such as trout, require relatively low daily mean temperatures of less than 22°C (Lyons, 1996) for survival and are particularly sensitive to temperature fluctuations. As urbanization continues to spread throughout the basin, mitigation of thermal impacts caused by increases in impervious surfaces will be increasingly important.

A summary of daily mean stream temperatures measured during sampled events in each phase of construction is given in table 4. Downstream temperatures were statistically higher than upstream temperatures, most likely because lack of overhead tree canopy in the area between the upstream and downstream stations subjects the stream to direct solar heating. To determine whether the downstream temperatures increased as a result of activity within the study area, a one-way analysis of variance (ANOVA) (Ott and Longnecker, 2001) test was used to identify differences between the means of independent samples. Test results showed no significant increases in stream temperature as a result of activity within the study area (at the 90-percent confidence level).

Ecologic Response

Ecologic response in terms of macroinvertebrate communities, fish communities, and habitat to construction of the residential subdivision is discussed in the following sections below.

Macroinvertebrate and Fish Communities

A total of 10 macroinvertebrate samples were collected for this study from October 1999 to October 2002. HBI values (fig. 12) ranged from 4.19 (very good water quality) to 4.76 (good water quality). No significant differences (P=0.05) were detected either between sampling sites or before and after development. Results indicate

Table 4. Event mean temperature of Brewery Creek at the upstream and downstream monitoring stations during three phases of construction, Cross Plains, Wis.

[°C, degrees Celsius; Std Dev, standard deviation]

Temperature °C								
Preconstruction			Land disturbance			Home construction		
Event date	Upstream	Downstream	Event date	Upstream	Downstream	Event date	Upstream	Downstream
02/22/00	4.1	4.3	05/10/01	14.4	15.1	04/07/02	6.3	6.4
04/19/00	9.0	9.5	05/21/01	13.4	13.7	04/18/02	12.0	13.1
05/17/00	11.4	11.7	05/23/01	11.3	11.5	04/24/02	9.2	9.9
05/30/00	16.0	16.2	06/05/01	10.8	10.8	04/27/02	7.0	7.1
06/04/00	13.0	13.3	06/11/01	16.8	17.5	05/01/02	9.1	9.4
06/13/00	15.8	16.1	08/01/01	21.0	21.9	05/09/02	11.8	12.5
07/02/00	17.1	17.7	08/22/01	15.2	16.4	05/11/02	8.6	8.9
07/10/00	18.0	18.8	09/17/01	13.3	13.7	05/28/02	15.5	15.7
08/05/00	16.1	16.6	09/19/01	14.1	14.3	06/03/02	11.8	12.0
08/17/00	14.6	15.1	09/23/01	13.1	13.3	06/04/02	13.0	13.2
09/11/00	16.1	16.5	10/22/01	9.8	10.0	07/22/02	16.8	18.0
09/22/00	11.8	12.0	11/24/01	9.8	9.9	08/11/02	16.8	18.0
04/11/01	8.8	9.1	12/12/01	6.0	6.0	08/21/02	15.6	16.4
			02/18/02	3.8	4.0	09/02/02	15.7	16.4
			03/08/02	3.5	3.7			
Mean	13.2	13.6	**Mean**	11.7	12.1	**Mean**	12.1	12.6
Median	14.6	15.1	**Median**	13.1	13.3	**Median**	11.9	12.8
Std Dev	4.0	4.1	**Std Dev**	4.8	5.0	**Std Dev**	3.6	3.9
Maximum	18.0	18.8	**Maximum**	21.0	21.9	**Maximum**	16.8	18.0
Minimum	4.1	4.3	**Minimum**	3.5	3.7	**Minimum**	6.3	6.4

that dissolved-oxygen concentrations were consistently sufficient to support a diverse macroinvertebrate community and that organic contamination was not appreciable throughout the 3-year study period. Interpretation of the empirical results, relative to Hilsenhoff's scale, was that the degree of organic pollution ranged from "possible slight to some" during the study period.

Fish communities were sampled six times for this study. A total of 10 species were collected and identified at least once. The list includes brown trout, **creekchub**, **fathead minnow**, **golden shiner**, **white sucker**, **yellow bullhead**, black bullhead, brook stickleback, **green sunfish**, and bluegill. The species in bold are considered tolerant to environmental degradation. No intolerant species were found. The proportion of tolerant individuals ranged from 54 percent to 78 percent (fig. 13) and was the primary reason IBI scores remained low throughout the entire study. IBI scores of 10 or 20 (fig. 13) were both within the "poor" range. Brown trout were relatively abundant in Brewery Creek with numbers ranging from 22 to 46 (fig. 14) and percentages ranging from 16 percent to 46 percent (fig. 13). Brown trout size structure was variable during the study, with greater numbers of juvenile individuals from 1999 through 2001 and greater numbers of adults in 2002 and 2003. Trout of legal keeping size (greater than 9 in. long) ranged from 1 out of 37 in 2001 to 15 out of 26 in 2002 and 15 out of 44 in 2003 (fig. 14). The largest brown trout was 15.75 in. long.

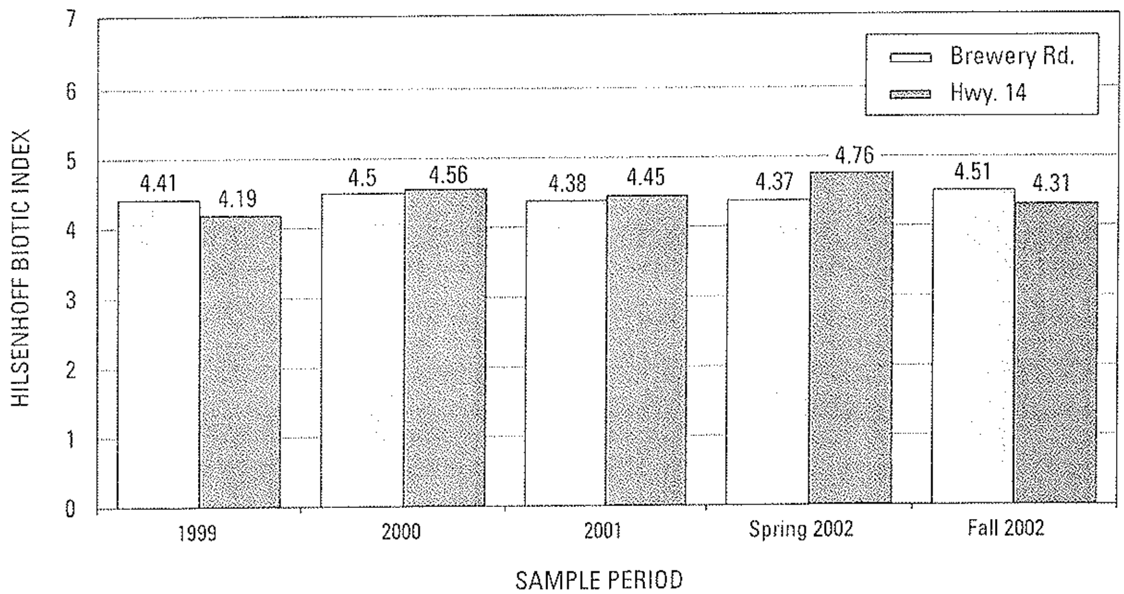

Figure 12. Hilsenhoff Biotic Index scores at two locations on Brewery Creek, Cross Plains, Wis.

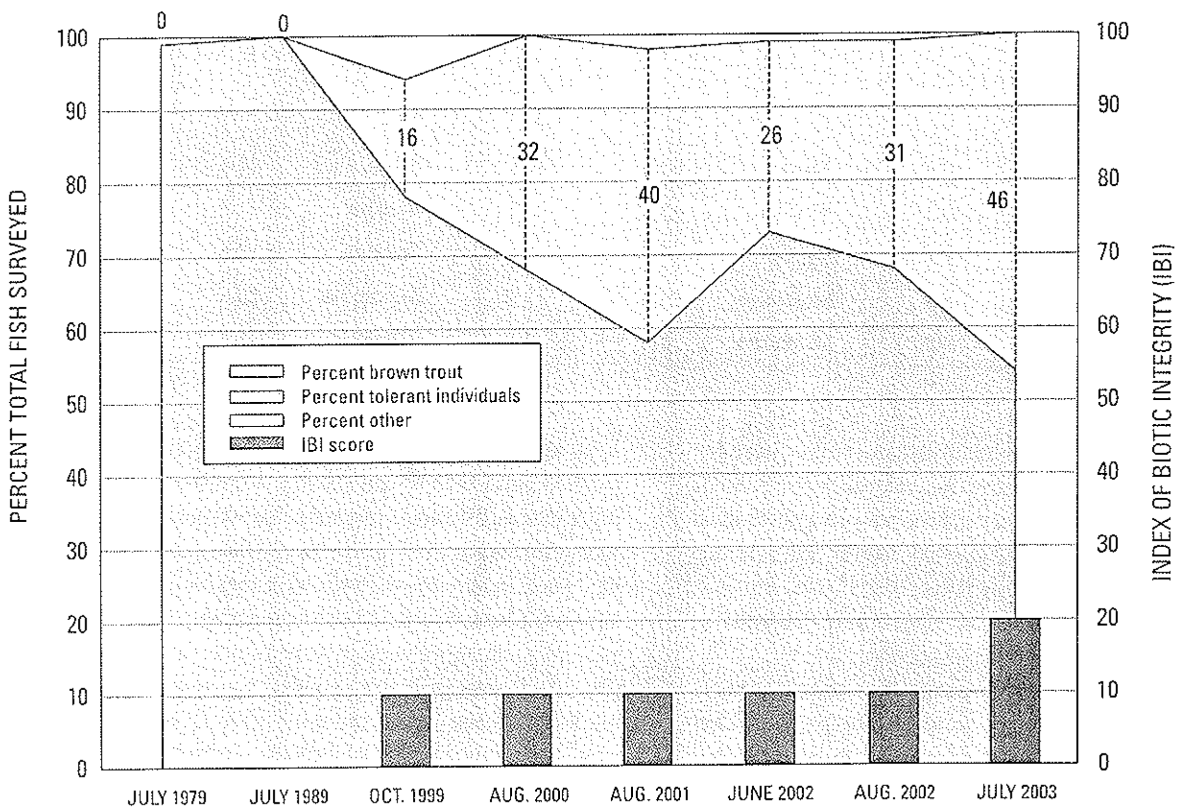

Figure 13. Results of fish-shocking surveys and subsequent Index of Biotic Integrity in Brewery Creek, Cross Plains, Wis. (1999–2003). [Pre-1999 data from Fago, 1979; and Wisconsin Department of Natural Resources, 1989].

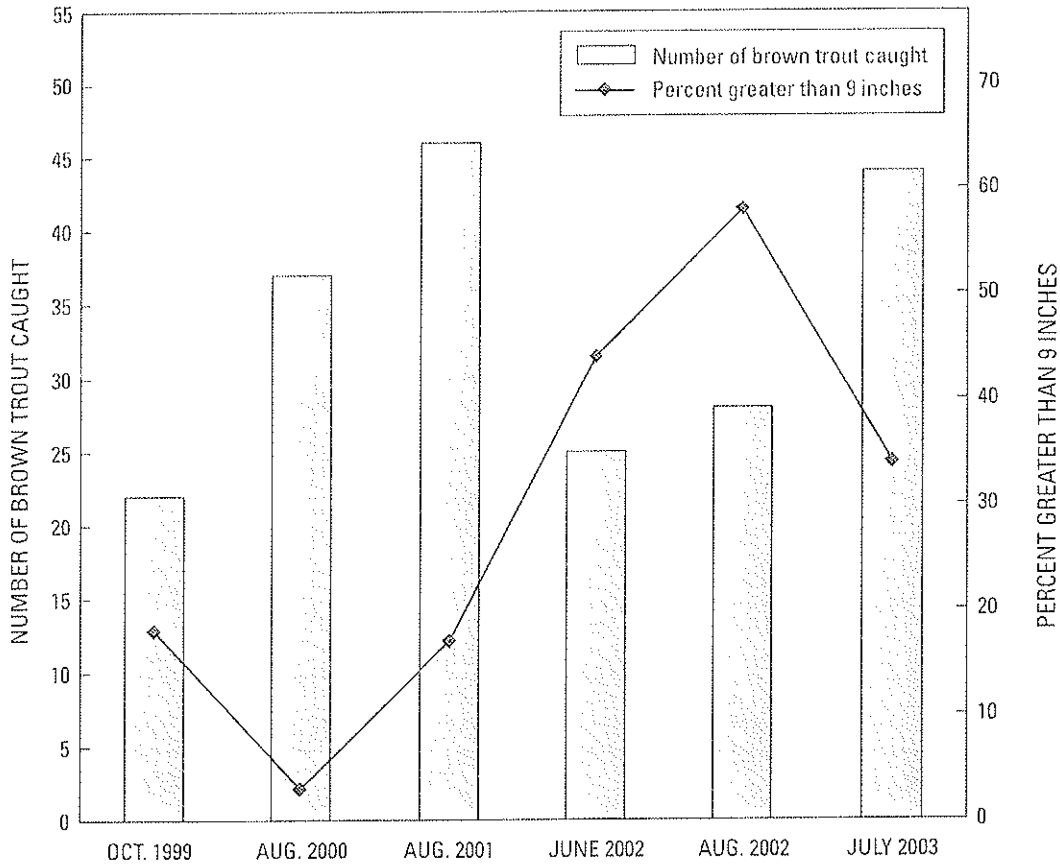

Figure 14. Number of brown trout measured during fish-shocking surveys in Brewery Creek, Cross Plains, Wis. (1999–2003).

Low IBI scores reflected a combined absence of intolerant species and a general lack of coldwater indicators (with the exception of brown trout) and presence of numerous tolerant species. Although brown trout size structure did change during the study, the overall fish-community structure remained the same.

Differences in the macroinvertebrate and fish sample results are related to different metric objectives. The HBI is based on macroinvertebrate tolerances to organic pollution, whereas the coldwater IBI is based on fish tolerances to a wide variety of environmental factors including temperature and physical habitat. The combination of these results indicate that organic-contaminant loading is not a limiting factor in Brewery Creek but that overall habitat is in poor condition.

Beginning in the mid-1980s, Brewery Creek became the focus of water-quality evaluation as part of the Black Earth Creek Priority Watershed Project. Historical water-quality, macroinvertebrate, and fish-community data indicated that Brewery Creek was appreciably impaired. Best management practices implemented as part of the Black Earth Creek Priority Watershed Project did not affect total-phosphorus or suspended-sediment concentrations over time, but ammonia concentrations did decline (Graczyk and others, 2003). This result suggests that organic loading declined. Such a decline is also reflected by a trend (R^2 = 0.58) of improved HBI scores (fig. 15). Although fish-community data from Brewery Creek are limited, surveys done before 1990 indicate that the stream was degraded (fig. 13). No trout were found during surveys in 1979 or 1989, and IBI scores were 0 or "very poor". Beginning in 1999, substantial brown trout numbers were found in every survey, and coldwater IBI scores improved slightly. Although the overall fish community is still considered unbalanced, the recent fish-shocking surveys are consistent with macroinvertebrate collections and indicate improved water quality and habitat conditions in Brewery Creek.

The improved water-quality and habitat conditions in Brewery Creek are beneficial for managing Black Earth Creek trout fisheries. Not only have organic loads declined in Brewery Creek, the small tributary also provides habitat for migrating brown trout and forage populations. During the 3-year study, fisheries in Brewery Creek were not affected as a result of the new subdivision development.

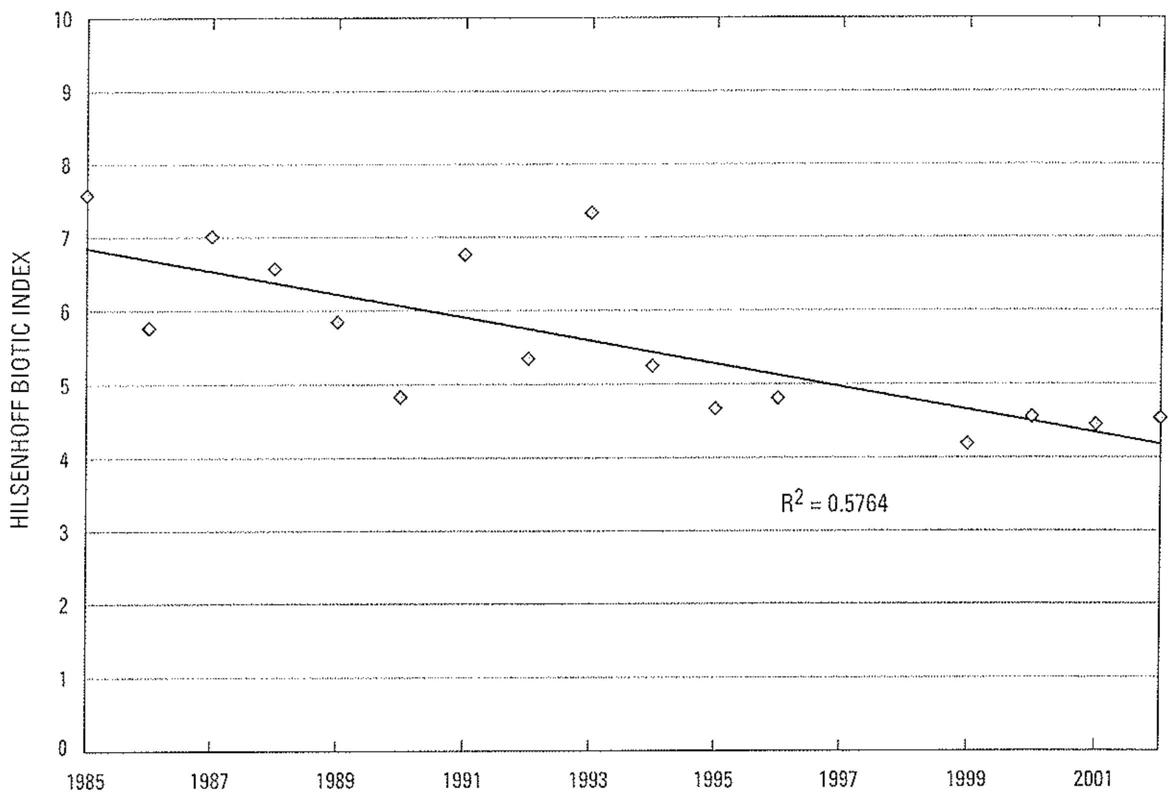

Figure 15. Trend in Hilsenhoff Biotic Index scores in Brewery Creek at Highway 14, Cross Plains, Wis. (1985–2002).

Habitat

Preconstruction results from sampling locations H1 and H2 yielded Habitat Index Scores of 40 and 45, respectively (table 5), which correspond to "fair" in the qualitative assessment. Scores from the postconstruction evaluation were 40 and 35 at H1 and H2, respectively, but the rating for H2 was still "fair." The 10-point change at H2 was due to 5-point changes in two of the assessment metrics, width-to-depth ratio and riffle-to-riffle ratio. The change in width-to-depth ratio resulted from placement of a large double-celled culvert within the habitat station (fig. 16).

Mean stream width and depth also were computed for each habitat station (table 5). The preconstruction mean stream widths indicate a second-order stream (Strahler, 1957). Postconstruction mean stream widths indicate a substantial increase for both stations. The change was greater at H2, where the difference of 3.3 feet amounted to a 53-percent increase. Changes in mean stream depth from preconstruction to postconstruction were, in contrast, insubstantial and opposite for the two stations, H1 deepening by 0.13 feet and H2 becoming shallower by 0.13 feet. The changes at H2 were, again, attributable to the placement of the large culvert.

The mean depth of fines over the coarse sand and silt substrate at both stations ranged from 0.26 to 0.35 feet (table 6). At H1, a slight postconstruction increase in mean depth of fines was noted. At H2, however, the depth of 4.86 feet was nearly double the preconstruction value.

The exact cause for the increase is difficult to determine. Sediment influx as a result of construction activity of the St. Francis development is one possible scenario; however, results of water-quality sampling during storm events did not substantiate this scenario. Other activities or occurrences within the study area may have contributed to an increase in the depth of fines, including removal of the weir structure during spring 2003, contribution of fines from upstream sources, and failing streambanks. Data from additional habitat sites would be needed to identify other potential sources of sediment to Brewery Creek.

Table 5. Physical habitat data for Brewery Creek, St. Francis residential subdivision, Cross Plains, Wis.

[ft, feet]

Site	Mean stream width (ft)	Mean stream depth (ft)	Width/depth ratio	Habitat score
H1 Preconstruction	9.3	0.9	10.3	40/FAIR
H2 Preconstruction	6.3	1.0	6.3	45/FAIR
H1 Preconstruction	10.2	1.0	10.2	40/FAIR
H2 Preconstruction	9.6	0.9	10.7	35/FAIR

Table 6. Depth of fines data analysis for Brewery Creek, St. Francis residential subdivision, Cross Plains, Wis.

[all depths in feet]

Site	Mean	Maximum	Median
Preconstruction H1	0.35	1.18	0.33
Preconstruction H2	0.26	0.92	0.23
Preconstruction H1	0.44	1.18	0.43
Preconstruction H2	0.49	1.18	0.39
Difference H1	0.09	0	0.10
Difference H2	0.23	0.26	0.16

Geomorphic Response

Results of the bank-pin surveys indicated failing banks at most sites. Bank pins in cross sections 1–8 (straightened reach) averaged 43.6 mm of deposition, whereas bank pins at cross sections 9–14 (meandering reach) averaged 26.4 mm of deposition at the conclusion of the study period. Bank material on Brewery Creek is primarily cohesive alluvial silt loam, making exposed banks susceptible to erosion. Although measurements indicated deposition, this was due to bank failure rather than sediment deposition on the banks. Streambank erosion processes are classified into two basic groups: gravitational or mechanical failures and tractive-force failures (O'Neill and Kuhns, 1994). The failing banks on Brewery Creek were indicative of gravitational failure, given low flows and the fine-grained cohesive soils. An example of streambank failure on Brewery Creek is shown in figure 17.

Results of the Rosgen Stream Classification showed only minor variations from 2001 and 2003 classifications (table 7). Bankfull widths and average depths decreased, whereas the width depth (w/d) ratios and entrenchment ratios increased. These changes were due in part to the placement of two large culverts (fig. 16) directly upstream from cross-section 8 and lower annual average precipitation in 2003. At cross section 1, the stream type went from a "G" to an "F" (Rosgen, 1996) with the dominant bed material changing from gravel to silt-clay. This difference can be attributed to removal of the V-notch weir at the upstream water-quality station in May 2003. During removal of the weir, soft sediment that had been deposited upstream from the structure was flushed and allowed to travel downstream. Cross section 9, in the uppermost part of the meandering section, did not change in stream type, but an increase in size of bed material from silt-clay to more gravel was noted.

Results of the Wolman Pebble Count Procedure indicated an increase in the cumulative percentage of fine-grained sediment at all transect survey locations. For example, differences in size-class distribution at cross section 13 can be seen in figure 18.

In summary, results of the fluvial geomorphology classifications and analyses do not indicate that the St. Francis Development on Brewery Creek contributed to changes in stream characteristics. Stream hydrology may have been altered slightly by removal of the weir and placement of the culverts as part of the road construction, but it is difficult to quantify the effects of these actions, if they can be quantified at all. No significant changes were detected after analyzing yearly stream-survey data.

Erosion of the streambanks was the primary source of increased fine-grained sediment noted during annual

Figure 16. Culverts placed in Brewery Creek for road crossing (view looking upstream), Cross Plains, Wis. Note difference between the culverts and the channel width directly downstream.

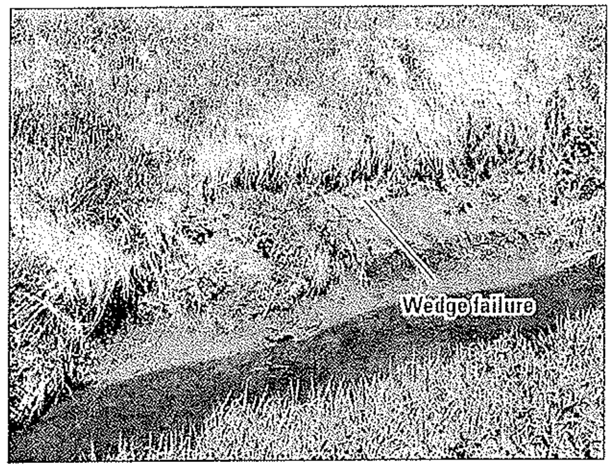

Figure 17. Example of gravitational streambank erosion in Brewery Creek, Cross Plains, Wis. Wedge failure leads to mass wasting of bank.

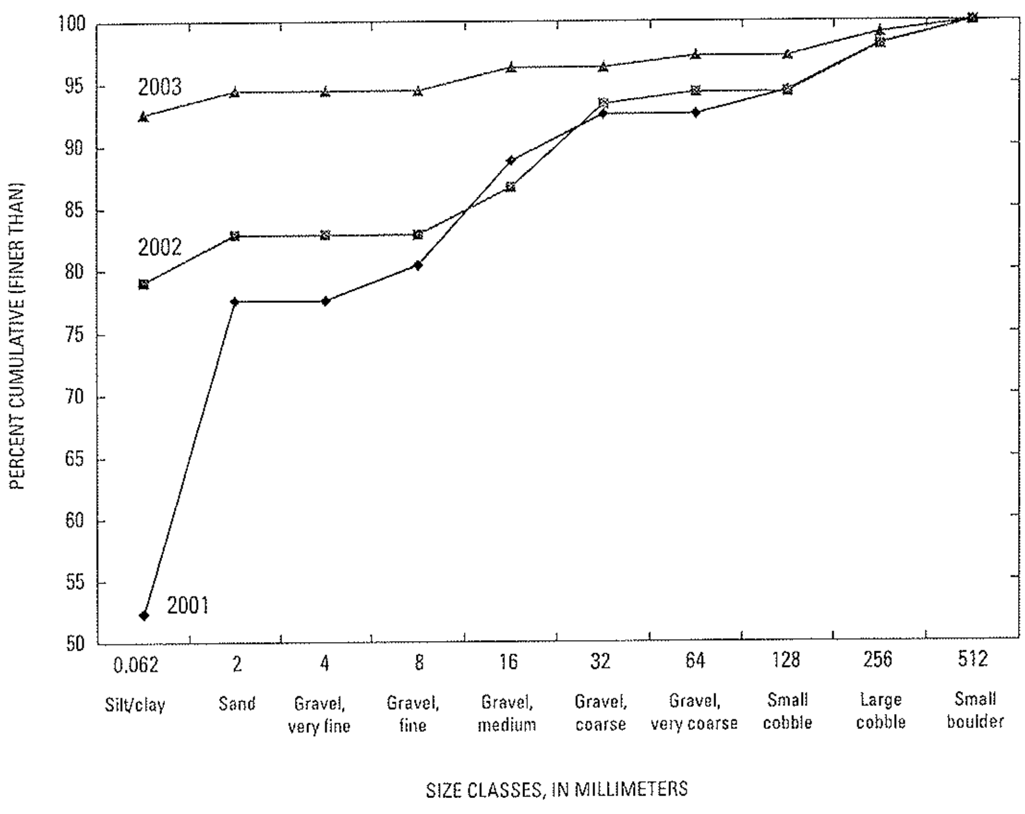

Figure 18. Results of Wolman Pebble Count at cross section 13 in Brewery Creek, Cross Plains, Wis. (2001–03).

pebble counts. Based on flow regimes and overall decreases in sediment yield from the construction site, the percentage of fine-grained sediment should have decreased corresponding to flows and constituent loading. In the loess area of the midwestern United States, however, bank material has been reported to contribute as much as 80 percent of the total sediment eroded from incised channels (Simon and others,1996). Analysis with Rosgen's stream classification indicated that channels were entrenched to slightly entrenched, making them more susceptible to erosion processes.

In addition to bank erosion, removal of the V-notch at the upstream water-quality station in the spring of 2003 likely contributed to an increase in fine-grained sediments. The weir was in the upstream segment of the study area (channelized reach) and released sediment downstream when it was removed. Data collected in 2001 and 2002 were very similar in results, whereas 2003 data indicated a significant increase in fines at all measured cross sections.

Summary and Conclusions

The U.S. Geological Survey (USGS), in cooperation with the Dane County Land Conservation Department (LCD) and the Wisconsin Department of Natural Resources (WDNR), conducted a multidisciplinary study incorporating streamflow, water-quality sampling, and physical, ecological, and geomorphic metrics to assess instream effects from construction of a residential subdivision on Brewery Creek, Dane County, Wis. An upstream/downstream (above and below) approach was used to isolate any changes caused by the study area over a period of 3 years (2001–03).

Collectively, the stormwater-management and erosion-control BMPs used at the St. Francis residential subdivision provided sufficient protection against degradation to Brewery Creek. Additionally, proper implementation and maintenance of the erosion-control and stormwater-management plan were critical components to reducing stormwater runoff. Results from this project will serve as an example for Dane County developers and builders of how to meet stormwater standards detailed in the Dane County Ordinance.

Erosion and stormwater-management controls implemented within the study area were effective at controlling runoff and solids transport during construction activity. Downstream event volumes, loads, and temperature were significantly greater than upstream volumes, loads, and temperature during three phases of construction: preconstruction, land disturbance, and home construction. The effectiveness of stormwater-management and erosion-control BMP systems was measured by evaluating the change in magnitude of differences between the downstream and upstream stations from one phase of construction activity to the next. The median difference between downstream and upstream storm volumes decreased (60 percent) from the preconstruction phase to the land-disturbance phase and slightly increased (9 percent) from the land-disturbance phase to the home-construction phase. The median differences for total and suspended solids load indicated a similar trend from preconstruction to land-disturbance phases with decreases of 52 and 72 percent, respectively. Both total and suspended solids load continued to decrease in the transition, from land-disturbance to home-construction phases; by 22 and 37 percent, respectively. Extreme data variability hampered statistical interpretation. Additional storm volume and load data could reduce variability and improve the statistical significance when determining an increase or decrease in volume or load from the study area.

Although daily mean stream temperature at the downstream monitoring station was consistently higher than at the upstream monitoring station during each phase, there was no statistical evidence to suggest an increase in stream temperature as a result of activity within the study area. Stream temperatures were most likely affected by direct solar heating because of a lack of overhead tree canopy between the downstream and upstream stations on Brewery Creek. Tree canopy was not altered during construction activity in the study area and was not considered part of the storm-runoff BMP system.

Ecologic indices for macroinvertebrate and fish communities indicate there were no negative effects to water quality and fisheries in Brewery Creek as a result of activity within the St. Francis subdivision. Macroinvertebrate sampling results (HBI value) on Brewery Creek ranged from "very good" to "good" water quality with no significant differences during any phase of construction activity. Results for fish-community composition, however, fell within the "poor" range (IBI value) during each year of testing. A general absence of intolerant species, with the exception of brown trout, reflects the low IBI values. The combination of these results suggests that organic loading is not a limiting factor in Brewery Creek but that overall fish habitat is in poor condition.

Habitat measurements did not change significantly from preconstruction to postconstruction phases. Although installation of a double-celled culvert in Brewery Creek most likely altered the width-to-depth ratio in that reach, the overall habitat rating remained "fair". Installation of the culvert may also have caused changes in mean stream width and depth. These changes were a result of modifications to the stream itself and do not reflect changes caused by surface runoff because of activities in the study area.

Fluvial geomorphology classifications, including channel cross sections, bed- and bank-erosion surveys, and pebble counts did not indicate that stream geomorphic characteristics were altered by home-construction activity in the study area. Increases in fine-grained sediment at various cross sections were attributed to instream erosion processes, such as bank slumping, rather than increases in sediment delivery from the nearby construction site. This result was further substantiated by the reduction of storm runoff from the construction site during each phase of the study. Additional sediment was introduced to the stream by way of removal of the V-notch weir at the upstream monitoring station in spring 2003.

Acknowledgments

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Appendix

Table A1. Preconstruction-phase precipitation data, Brewery Creek, Cross Plains, Wis.

[-, storm duration does not allow for intensity computation; in/hr, inches per hour]

Start date/time	End date/time	Total rain (inches)	5-minute intensity (in/hr)	10-minute intensity (in/hr)	15-minute intensity (in/hr)	30-minute intensity (in/hr)	60-minute intensity (in/hr)	Erosivity index
10/01/99 21:05	10/02/99 04:30	.36	.24	.18	.16	.12	.10	.27
10/03/99 12:15	10/03/99 18:00	.21	.12	.12	.12	.10	.09	.13
10/16/99 01:20	10/16/99 07:10	.25	.48	.42	.36	.26	.18	.44
11/10/99 14:45	11/10/99 18:30	.80	1.92	1.86	1.84	1.10	.72	7.83
11/23/99 01:45	11/23/99 12:40	.99	.84	.66	.52	.36	.21	2.52
12/03/99 10:55	12/03/99 18:40	.31	.12	.12	.12	.12	.09	.23
12/04/99 15:00	12/04/99 23:30	.12	.12	.06	.08	.06	.05	.04
12/09/99 11:00	12/09/99 16:40	.15	.12	.12	.08	.08	.06	.07
01/09/00 20:30	01/10/00 07:55	.13	.12	.06	.08	.06	.04	.05
02/15/00 12:35	02/15/00 13:50	.16	.24	.24	.20	.18	.14	.19
02/24/00 02:40	02/24/00 10:30	.31	.12	.12	.12	.10	.08	.19
02/25/00 18:10	02/26/00 01:25	.66	1.32	.96	.72	.42	.27	1.94
03/08/00 10:40	03/08/00 17:50	.20	.72	.60	.52	.30	.16	.46
03/09/00 03:25	03/09/00 08:45	.13	.12	.12	.12	.10	.07	.08
03/15/00 12:35	03/15/00 15:30	.13	.12	.12	.12	.08	.06	.06
03/19/00 13:05	03/20/00 05:35	.34	.12	.12	.08	.08	.06	.17
03/26/00 16:15	03/26/00 18:35	.11	.24	.24	.20	.14	.08	.10
04/08/00 13:20	04/08/00 15:15	.28	.36	.36	.36	.32	.25	.64
04/19/00 07:35	04/21/00 00:40	1.67	.96	.72	.64	.42	.38	5.03
04/23/00 00:15	04/23/00 09:30	.46	.24	.18	.16	.14	.14	.41
05/08/00 08:25	05/08/00 10:20	.13	.48	.42	.36	.24	.12	.23
05/11/00 22:35	05/12/00 09:20	.14	.24	.24	.20	.10	.07	.09
05/17/00 12:50	05/20/00 07:35	5.04	4.68	4.38	3.80	2.42	1.24	101.33
05/26/00 22:30	06/01/00 23:30	5.07[1]	11.52	6.60	4.44	2.24	1.36	103.42
06/04/00 06:25	06/05/00 06:55	.88	.36	.24	.20	.20	.19	1.13
06/12/00 06:00	06/12/00 11:10	.20	.36	.36	.32	.26	.15	.36
06/13/00 15:15	06/14/00 02:40	2.71	3.00	2.88	2.44	1.52	.87	37.54
06/16/00 03:20	06/16/00 05:40	.11	.12	.12	.12	.10	.06	.07
06/20/00 04:35	06/20/00 16:00	.70	.96	.90	.76	.50	.31	2.58
06/24/00 14:00	06/24/00 18:50	.29	.24	.18	.16	.14	.13	.25
06/26/00 08:50	06/26/00 10:00	.11	.36	.30	.20	.12	.10	.09
06/28/00 06:20	06/28/00 10:35	.18	.24	.18	.16	.12	.09	.13
07/02/00 19:35	07/02/00 21:15	.99	3.48	3.12	2.68	1.64	.90	15.65
07/09/00 06:20	07/09/00 10:15	.42	.48	.36	.32	.24	.22	.69
07/10/00 03:40	07/10/00 08:45	.73	.84	.72	.68	.44	.30	2.34
07/20/00 17:00	07/20/00 17:15	.14	.96	.78	.56	-	-	-
07/28/00 17:35	07/28/00 22:50	.20	.60	.48	.40	.30	.18	.44
07/30/00 16:05	07/30/00 16:20	.14	.96	.78	.56	-	-	-
08/05/00 11:15	08/05/00 22:10	1.81	3.12	3.00	2.80	2.06	1.39	34.29

Table A1. Preconstruction-phase precipitation data, Brewery Creek, Cross Plains, Wis.—Continued

[-, storm duration does not allow for intensity computation; in/hr, inches per hour]

Start date/time	End date/time	Total rain (inches)	5-minute intensity (in/hr)	10-minute intensity (in/hr)	15-minute intensity (in/hr)	30-minute intensity (in/hr)	60-minute intensity (in/hr)	Erosivity index
08/12/00 19:50	08/12/00 21:15	.13	.12	.12	.12	.12	.11	.10
08/13/00 06:30	08/13/00 09:35	.14	.36	.30	.28	.18	.11	.17
08/16/00 20:20	08/17/00 09:05	1.00	1.20	1.02	.96	.72	.50	5.48
08/26/00 07:30	08/26/00 10:05	1.14	2.88	2.34	1.84	1.28	.91	12.99
09/03/00 07:05	09/03/00 08:30	.28	1.08	.72	.56	.36	.24	.76
09/11/00 07:40	09/11/00 22:05	1.08[1]	2.04	1.80	1.48	.90	.77	8.59
09/14/00 00:45	09/14/00 06:40	.22	.36	.30	.28	.20	.10	.29
09/19/00 17:00	09/19/00 23:55	.54	.84	.54	.40	.28	.22	1.04
09/22/00 09:20	09/22/00 23:30	.64	.36	.30	.28	.18	.17	.75
10/03/00 19:30	10/03/00 23:45	.17	.24	.18	.16	.12	.10	.13
10/05/00 16:10	10/05/00 20:00	.16	.24	.18	.16	.12	.07	.12
10/23/00 08:20	10/23/00 14:25	.29	.24	.18	.16	.12	.10	.22
11/06/00 13:00	11/07/00 00:30	.89	.48	.36	.32	.24	.18	1.41
11/09/00 09:50	11/09/00 16:30	.15	.48	.24	.16	.08	.06	.08
11/24/00 11:25	11/24/00 14:15	.25	.24	.18	.16	.14	.11	.22
12/15/00 20:10	12/16/00 06:45	.35	.24	.18	.16	.12	.08	.26
12/18/00 09:25	12/18/00 22:20	.29	.12	.12	.08	.06	.06	.11
12/28/00 19:45	12/29/00 19:05	.22	.12	.06	.08	.04	.03	.05
01/14/01 01:45	01/14/01 09:55	.24	.12	.12	.12	.12	.09	.18
01/29/01 11:30	01/29/01 23:05	.86	.36	.30	.28	.22	.18	1.21
02/07/01 21:30	02/08/01 04:15	.24	.36	.36	.28	.26	.18	.43
02/08/01 15:25	02/09/01 17:55	1.34	.48	.42	.36	.32	.29	2.89
02/24/01 06:20	02/24/01 20:10	.23	.12	.12	.08	.08	.07	.11
03/12/01 07:45	03/12/01 11:30	.14	.12	.12	.08	.08	.07	.07
03/31/01 14:15	03/31/01 17:15	.27	.24	.18	.16	.14	.13	.24
04/05/01 13:15	04/05/01 17:35	.31	.72	.42	.36	.28	.15	.64
04/08/01 23:20	04/09/01 04:35	.76	.36	.36	.32	.28	.24	1.46
04/10/01 22:50	04/11/01 15:20	.73	1.20	.78	.68	.50	.31	2.82
04/20/01 02:15	04/20/01 06:10	.48	.36	.30	.28	.24	.20	.77
04/21/01 00:10	04/21/01 04:55	.44	1.44	.72	.56	.38	.23	1.37

[1] storm defined using 12-hour interval

Table A2. Land-disturbance-phase precipitation data, Brewery Creek, Cross Plains, Wis.

[-, storm duration does not allow for intensity computation; in/hr, inches per hour]

Start date/time	End date/time	Total rain (inches)	5-minute intensity (in/hr)	10-minute intensity (in/hr)	15-minute intensity (in/hr)	30-minute intensity (in/hr)	60-minute intensity (in/hr)	Erosivity index
05/01/01 04:05	05/01/01 07:10	.15	.36	.30	.28	.22	.13	.23
05/03/01 18:30	05/04/01 08:35	.37	.36	.30	.28	.18	.12	.43
05/06/01 19:35	05/07/01 10:50	.46	.48	.36	.36	.26	.21	.83
05/10/01 00:55	05/10/01 03:05	.15	.36	.30	.28	.20	.13	.21
05/10/01 19:45	05/11/01 05:15	.60	1.68	1.50	1.16	.70	.41	3.44
05/20/01 23:55	05/21/01 12:20	2.02	1.92	1.74	1.52	1.04	.71	17.33
05/22/01 11:20	05/23/01 16:30	.54	.48	.48	.32	.18	.11	.65
05/31/01 15:20	06/01/01 07:30	.42	.24	.18	.12	.10	.08	.26
06/01/01 16:55	06/01/01 20:20	.45	1.32	.78	.60	.40	.29	1.36
06/05/01 01:30	06/05/01 13:00	.73	1.32	1.02	.80	.54	.41	2.97
06/09/01 21:35	06/10/01 05:30	.28	.72	.54	.44	.26	.13	.56
06/11/01 22:00	06/12/01 05:30	2.07	2.40	2.22	2.04	1.74	1.31	33.12
06/14/01 11:40	06/14/01 22:55	.14	.72	.48	.32	.16	.08	.17
06/15/01 05:40	06/15/01 10:45	.16	.24	.18	.16	.08	.08	.08
06/18/01 03:00	06/18/01 11:55	.46	.48	.42	.36	.22	.19	.69
06/21/01 18:50	06/22/01 00:15	.33	.48	.42	.44	.34	.26	.81
07/17/01 08:20	07/17/01 13:45	.55	3.00	1.86	1.40	.80	.52	3.94
07/18/01 07:15	07/18/01 08:30	.98	3.72	3.24	2.76	1.74	.96	16.70
07/24/01 20:25	07/25/01 02:00	.24	.72	.48	.32	.16	.09	.26
08/01/01 18:00	08/02/01 08:00	9.56	5.40	5.10	4.76	3.84	2.74	235.11
08/09/01 17:10	08/09/01 17:25	.11	1.08	.60	.44	-	-	-
08/15/01 15:25	08/16/01 07:30	.50	.24	.24	.20	.14	.09	.43
08/22/01 06:40	08/22/01 13:05	.20	.24	.18	.20	.16	.08	.21
08/24/01 19:10	08/26/01 01:40	1.31	2.28	1.98	1.44	1.08	.84	12.09
08/27/01 04:20	08/27/01 06:30	.16	.48	.30	.24	.14	.09	.15
09/06/01 14:15	09/07/01 03:30	.14	.72	.42	.28	.14	.07	.14
09/07/01 12:20	09/07/01 12:40	.46	2.52	2.34	1.76	-	-	-
09/07/01 19:05	09/08/01 03:00	1.28	2.52	2.22	2.04	1.48	.81	17.45
09/09/01 09:00	09/09/01 19:50	.71	.36	.24	.24	.18	.16	.82
09/17/01 04:45	09/17/01 12:15	.57	.36	.30	.28	.24	.22	.90
09/18/01 23:45	09/19/01 14:35	1.06	.36	.30	.28	.22	.22	1.52
09/20/01 19:50	09/21/01 00:30	.24	.24	.24	.24	.24	.21	.40
09/22/01 22:30	09/23/01 16:40	1.73	1.08	.96	.88	.84	.63	10.80
10/09/01 23:35	10/10/01 12:55	.23	.24	.18	.16	.14	.08	.21
10/13/01 09:15	10/13/01 20:40	.20	.36	.24	.16	.08	.07	.10
10/22/01 14:40	10/22/01 22:05	1.17	.96	.84	.76	.60	.41	5.06
10/24/01 07:25	10/24/01 18:35	.25	.24	.24	.20	.18	.14	.29
11/13/01 02:50	11/13/01 10:05	.24	.36	.24	.20	.14	.12	.22
11/18/01 18:20	11/19/01 02:15	.25	.24	.12	.12	.10	.07	.16

Table A2. Land-disturbance-phase precipitation data, Brewery Creek, Cross Plains, Wis.—Continued

[-, storm duration does not allow for intensity computation; in/hr, inches per hour]

Start date/time	End date/time	Total rain (inches)	5-minute intensity (in/hr)	10-minute intensity (in/hr)	15-minute intensity (in/hr)	30-minute intensity (in/hr)	60-minute intensity (in/hr)	Erosivity index
11/23/01 18:00	11/24/01 11:00	.82	.60	.54	.48	.30	.19	1.62
11/26/01 17:20	11/27/01 02:45	.25	.36	.24	.20	.12	.08	.19
11/30/01 02:10	11/30/01 07:05	.25	.24	.18	.16	.14	.10	.22
12/05/01 03:05	12/05/01 07:55	.17	.24	.18	.20	.12	.10	.13
12/12/01 17:30	12/13/01 04:05	.58	.48	.42	.36	.28	.23	1.10
12/22/01 07:55	12/22/01 18:00	.23	.36	.30	.24	.18	.10	.27
02/01/02 10:05	02/01/02 13:20	.31	.24	.18	.16	.16	.13	.31
02/09/02 22:45	02/10/02 13:20	.50	.12	.12	.12	.12	.09	.37
02/18/02 22:10	02/20/02 19:55	1.68	.24	.24	.20	.18	.16	1.89
03/05/02 12:15	03/05/02 15:20	.20	.24	.18	.20	.16	.13	.20
03/07/02 22:00	03/09/02 09:45	.46[1]	.84	.54	.44	.24	.14	.80
03/19/02 13:50	03/19/02 22:10	.20	.12	.12	.12	.10	.08	.12

[1] storm defined using 12-hour interval

Table A3. Home-construction-phase precipitation data, Brewery Creek, Cross Plains, Wis.

[-, storm duration does not allow for intensity computation; in/hr, inches per hour]

Start date/time	End date/time	Total rain (inches)	5-minute intensity (in/hr)	10-minute intensity (in/hr)	15-minute intensity (in/hr)	30-minute intensity (in/hr)	60-minute intensity (in/hr)	Erosivity index
04/02/02 08:25	04/02/02 18:30	.25	.12	.12	.12	.10	.09	.15
04/07/02 03:40	04/09/02 06:40	1.36[1]	.36	.36	.32	.28	.14	2.40
04/12/02 00:25	04/12/02 02:20	.16	.24	.24	.20	.18	.11	.19
04/14/02 18:10	04/14/02 19:10	.19	1.08	.84	.64	.32	.19	.51
04/18/02 16:00	04/18/02 22:25	.66	1.44	1.32	1.08	.84	.46	4.74
04/21/02 03:15	04/22/02 03:00	.32	.36	.24	.24	.16	.08	.32
04/24/02 12:55	04/24/02 15:30	.39	.72	.66	.64	.58	.36	1.79
04/27/02 11:05	04/28/02 06:15	.70	.36	.30	.28	.18	.12	.79
05/01/02 12:20	05/02/02 00:20	.56	.36	.30	.28	.22	.15	.79
05/06/02 22:15	05/06/02 23:15	.31	1.32	1.14	1.00	.60	.31	1.67
05/08/02 22:20	05/09/02 07:45	.78	1.44	.90	.64	.64	.50	3.90
05/11/02 10:50	05/12/02 10:30	.83	.84	.42	.32	.28	.22	1.60
05/25/02 05:05	05/25/02 13:55	.76	.36	.36	.32	.30	.24	1.50
05/28/02 20:25	05/29/02 05:35	.30	.60	.54	.44	.36	.24	.79
06/02/02 16:30	06/03/02 10:15	.24	.24	.18	.16	.12	.09	.18
06/03/02 22:45	06/04/02 11:30	.36	.36	.36	.32	.24	.16	.56
06/10/02 18:55	06/10/02 20:50	.14	.24	.24	.24	.16	.11	.15
06/26/02 04:05	06/26/02 10:10	.39	1.20	.84	.68	.38	.21	1.10
07/08/02 12:05	07/08/02 12:45	.56	1.56	1.50	1.48	1.06	-	5.56
07/08/02 20:35	07/08/02 20:50	.10	.60	.54	.40	-	-	-
07/20/02 15:20	07/20/02 15:55	.55	2.28	2.16	1.68	1.08	-	5.75
07/22/02 00:35	07/22/02 07:25	1.16	3.48	2.46	2.12	1.28	.70	13.21
07/27/02 05:30	07/27/02 10:30	.21	.24	.18	.16	.10	.08	.13
07/27/02 23:05	07/27/02 23:15	.12	1.20	.72	-	-	-	-
08/04/02 02:25	08/04/02 10:35	.73	2.28	2.04	1.76	.98	.50	6.34
08/11/02 16:35	08/11/02 17:55	1.74	3.96	3.30	2.96	2.02	1.53	35.90
08/12/02 20:15	08/13/02 05:10	.43	.60	.42	.36	0.26	.16	.76
08/17/02 06:50	08/17/02 07:10	.32	1.56	1.44	1.12	-	-	-
08/21/02 18:00	08/22/02 13:05	.93[1]	2.28	2.10	1.60	.88	.45	6.62
09/02/02 03:45	09/02/02 08:15	1.05	1.56	1.38	1.20	.90	.57	7.73
09/10/02 12:15	09/10/02 13:25	.16	.24	.24	.20	.18	.14	.19
09/19/02 00:55	09/19/02 05:05	.35	.72	.42	.36	.22	.17	.54
09/19/02 12:45	09/19/02 20:35	.17	.72	.48	.48	.26	.14	.34
09/20/02 04:00	09/20/02 18:15	.28	.96	.72	.52	.28	.14	.57
09/28/02 21:45	0 9/29/02 05:35	.70	1.45	1.17	.93	.71	.36	3.99

[1] storm defined using 12-hour interval

Table A4. Quality-control results for water sampling at Brewery Creek, Cross Plains, Wis.

[mg/L, milligrams per liter; RPD, relative percent difference; NA, not applicable; <, less than; %, percent]

Date/time	Sample type	Total solids (mg/L)	Total solids (RPD)	Suspended solids (mg/L)	Suspended solids (RPD)
			UPSTREAM		
08/17/99 16:45	Blank	66	NA	48	NA
08/17/99 17:00	Blank	<7	NA	<5	NA
04/17/01 09:40	Blank	<20	NA	<2	NA
07/09/02 09:20	Blank	<50	NA	<2	NA
08/21/02 13:05	Replicate	454	4%	18	0%
08/21/02 13:06	EWI	438		18	
11/07/01 12:00	Manual	506	0%	52	10%
11/07/01 12:01	EWI	504		47	
08/21/02 13:00	Manual	494	12%	45	86%
08/21/02 13:06	EWI	438		18	
			DOWNSTREAM		
08/17/99 16:30	Blank	22	NA	<5	NA
04/19/01 09:00	Blank	<50	NA	<2	NA
07/09/02 09:00	Blank	<50	NA	<2	NA
12/12/01 19:40	Replicate	554	3%	110	8%
12/12/01 19:41	EWI	536		102	
08/21/02 12:55	Replicate	454	0%	17	11%
08/21/02 12:56	EWI	452		19	
03/06/00 09:25	Manual	482	0%	23	4%
03/06/00 09:20	EWI	482		22	
11/07/01 11:50	Manual	512	1%	52	2%
11/07/01 11:51	EWI	508		51	
08/21/02 12:48	Manual	462	2%	32	51%
08/21/02 12:56	EWI	452		19	

Appendix 3

Richard C. Lathrop and Kenneth W. Potter:
Alternative Urbanization Scenarios for an Agricultural
Watershed: Design Criteria, Social Constraints, and
Effects on Groundwater and Surface Water Systems
(Project Period 2000-2004)

Final Report

EPA Agreement Number: R-82801001-1
Title: Alternative Urbanization Scenarios for an Agricultural Watershed: Design Criteria, Social Constraints, and Effects on Groundwater and Surface Water Systems
Investigators: Richard C. Lathrop[1] and Kenneth W. Potter[2] (Co-Principal Investigators); Jean M. Bahr[2], Kenneth R. Bradbury[2], Steven R. Greb[1], James A. LaGro Jr.[2], Edward B. Nelson[1], Peter Nowak[2], and Joy B. Zedler[2] (Co-Investigators)
Institution: [1]Wisconsin Department of Natural Resources, Madison, Wisconsin; [2]University of Wisconsin-Madison, Wisconsin
Research Category: Water and Watersheds
Project Period: February 2000 – July 2004

Research Objectives

This research focused on mitigating the impacts of urbanization in agricultural regions in which both humans and aquatic ecosystems greatly depend on groundwater. The goal was to fill critical knowledge gaps and extend/develop analytical and modeling tools to minimize hydrologic impacts of urbanization. We have considered the full range of relevant water issues, including storm runoff, groundwater depletion, wastewater treatment, eutrophication, and wetland degradation. We also have addressed the interaction among these issues and the social and political opportunities for, and constraints on, effective management. In this report we highlight six research objectives utilizing a comprehensive case study that evaluated the benefits of alternative management practices at the watershed scale. The key objectives evaluated are:

- Evaluate alternative management practices and patterns of urbanization by considering a range of urban development issues, including storm runoff, groundwater depletion, wastewater treatment, wetland degradation, thermal pollution, and eutrophication.

- Fill critical knowledge gaps and extend (or develop) analytical and modeling tools that will minimize the hydrologic and ecological impacts of urbanization.

- Construct comparable land use/water management scenarios for a test watershed (Pheasant Branch), including "low-impact development" designs, and evaluate their approximate economic costs, social/political acceptability, and hydrologic and ecological impacts.

- Examine urban impacts on wetlands, especially their biodiversity, and determine which native species can thrive in constructed urban bioretention wetlands or rain gardens.

- Evaluate farmer behaviors needed to reduce high soil P concentrations in agricultural lands that are likely to be converted to urban development.

- Evaluate the social and institutional barriers to low-impact development, and provide guidance to local governments and citizen groups for improving the management and protection of critical aquatic resources in rapidly urbanizing landscapes.

Much of the research was conducted as a case study in the North Fork of the Pheasant Branch subwatershed in the western basin of the Lake Mendota watershed (Fig. 1). The current land use in the Pheasant Branch subwatershed is largely agricultural, although urban expansion into the watershed is imminent. The watershed contains or influences several critical aquatic systems, including a large spring complex, wetlands, and Lake Mendota – the most significant lake in the county.

Hydrogeologic research

Hydrogeologic research conducted as part of the project is related to three objectives outlined in the original proposal: optimal siting and operation of municipal and other high capacity wells, evaluating groundwater quality and quantity tradeoffs between unsewered and sewered subdivisions, and identifying hydrogeologic controls on wetland biodiversity. The major results of each of these research efforts are described below.

Optimal well siting and operation. A major goal of this component of the research, conducted in the context of the Pheasant Branch watershed case study, was the development of a numerical model of groundwater flow with which effects of municipal pumping as well as enhanced infiltration practices could be quantitatively evaluated. Although an existing, county-scale numerical model had been previously developed, it was at a scale that was too coarse to simulate many of the springs and wetland areas of concern. In addition, the existing model generated a poor match to observed baseflow in many streams. Development of a refined model first required an improved understanding of the sources of water to major springs.

Initial conceptual models of spring flow were tested through field and modeling studies in the Nine Springs Creek watershed (immediately south of Madison). Geochemical analyses of springs and water from boreholes in that watershed indicated a bedrock rather than glacial sediment source for the springs (Swanson et al. 2001). Borehole testing in two existing wells and a nested pair of newly drilled bedrock wells revealed the discrete high permeability zones in one of the shallow bedrock units. Analytical and numerical modeling (Swanson and Bahr 2004) demonstrated that the steady spring flow observed in the Nine Springs Creek watershed could be supported by preferential flow through thin zones in shallow bedrock (Fig. 2).

Building on the initial conceptual model developed for the Nine Springs Creek watershed, additional bedrock wells were drilled near the major springs in our case study watershed (Pheasant Branch) and in the Token Creek watershed (eastern part of the larger Lake Mendota watershed). Interval packer tests in these wells revealed similar high permeability zones in the shallow bedrock (Fig. 3). The correlation over tens of kilometers between bedrock high permeability zones in these three watersheds is discussed in Swanson et al. (in review). Recognition of the potential for sandstone aquifers to contain such continuous preferential flow zones has important implications for managing groundwater resources and protecting water supplies from sources of contaminants.

The test bedrock well in the Pheasant Branch subwatershed also provided stratigraphic information that confirmed the presence of a regional aquitard (shale layer) separating the upper and lower bedrock aquifers. The effects of pumping by nearby municipal and other high capacity wells on water levels in the upper and lower bedrock aquifers were evaluated by examining continuous water level records from two zones of the test well separated using an inflatable packer. Comparison of the water level data to records of precipitation and pumping rates for nearby deep-aquifer wells revealed that pumping causes frequent cycling of water levels in the lower aquifer while the upper aquifer has relatively steady water levels that respond primarily to precipitation (Fig. 4). These results illustrate the effectiveness of the regional shale aquitard in isolating the lower bedrock aquifer and also confirm the hypothesis that steady spring flow rates are maintained by water discharging from the shallow bedrock.

A telescoped model of the Pheasant Branch watershed was then developed, incorporating a high permeability layer in the upper bedrock to simulate the effects of preferential bedrock flow zones. This model provided an improved calibration to spatial variations in groundwater discharge to streams and at springs. The model was used to simulate potential effects of urban expansion and increased groundwater pumping. Simulations of increased groundwater withdrawal based upon projected demand for the year 2020 resulted in relatively modest decreases in base flow of up to 12% in Pheasant Branch. Simulations with wells pumping from the lower aquifer showed decreases of less than 1% in spring flow, a result that was independent of the locations of the wells being pumped. However, decreases of approximately 7% in groundwater discharge to wetlands were found for simulations including either deep or shallow wells near the Pheasant Branch marsh wetland system. More significant impacts were simulated for scenarios incorporating decreases in recharge that would accompany increased impervious area from urban development: baseflow decreases up to 63% along Pheasant Branch and 22% at Pheasant Branch marsh. These results indicate the need for maintaining or enhancing local recharge in order to limit negative impacts on groundwater-fed aquatic ecosystems in this setting.

Water Quality Impacts of Unsewered Subdivisions. From the perspective of water quantity, subdivisions with on-site wastewater disposal (septic) systems have the advantage that water is returned to the aquifer locally rather than piped to a distant treatment plant for possible export to another watershed. However, such septic systems also serve as a source of contaminants that can be released to shallow groundwater. In urbanizing areas where the previous land use is agricultural, the contaminant sources associated with unsewered subdivisions replace former agricultural sources. This complicates the problem of quantifying the contaminant loading from unsewered subdivisions because measured contaminant concentrations may be from either current septic sources or remnants of past land use practices.

Our project, with additional funding from the State of Wisconsin, initiated a long-term monitoring program at a new unsewered subdivision that is currently being developed. Data from this project will allow quantification of contaminant loading both for conventional and novel septic technologies through a direct comparison of water quality prior to and following conversion of agricultural land to an unsewered residential community. A monitoring network of 19 wells installed prior to construction of any homes provided over a year of data with which to evaluate spatial and temporal variations in background concentrations of nitrate and other constituents. Temporal variations in nitrate and chloride are large. For example, both nitrate and chloride concentrations in the wells decreased during the spring recharge period whereas earlier in the spring chloride concentrations in some of the wells increased due to infiltration of water containing road salt. As discussed in Wilcox et al. (in revision for Ground Water), these variations can be explained by seasonal variations in recharge, local loading patterns, aquifer heterogeneities, and surface topography, all of which must be adequately characterized for a given site in order to distinguish between urbanization and agriculture sources of groundwater contaminants.

Hydrogeologic controls on wetland biodiversity. Assessing the impact of urban disturbances on wetland biodiversity, and designing effective restoration strategies, requires adequate understanding of the controls on biodiversity in undisturbed wetlands. Among important controls are hydrogeologic and geochemical conditions. As part of our project, we conducted a detailed study of a relatively undisturbed wetland in which sharp transitions of plant communities from fen, to sedge meadow and shallow marsh occurred with minimal topographic relief. Subsurface coring revealed a heterogeneous stratigraphy of peat and glacial deposits. The location and thickness of a buried silt loam layer correlated with the locations of vegetation transitions. Major ion and stable isotope signatures of water from shallow wells also vary across the site as a function of the degree of mixing between discharging regional groundwater and local precipitation.

The conceptual model developed on the basis of data collected is illustrated in Fig. 5. The subsurface stratigraphy controls the rate of groundwater discharge, which in turn affects water chemistry. The marsh vegetation is adapted to frequent and long duration inundation that occurs due to limited infiltration through the silt during high water levels. Cattails, the dominant species in the marsh, are tolerant of a range of chemical conditions. In contrast, vegetation in the fen and sedge meadow is more sensitive to hydroperiods and variations in water chemistry. The results of this work have important implications for attempts at wetland creation to substitute for wetlands that might be degraded or lost during urban development. Because hydroperiods and water chemistry can be largely controlled by subsurface stratigraphy, creating the proper conditions to establish sensitive vegetation communities may be precluded in the absence of subsurface conditions that allow steady groundwater discharge. This implies that careful management of remaining fens and sedge meadows is critical to preserving the functions they perform.

Impacts of altered hydrologic conditions on wetland biodiversity

The spread of invasive plants into natural and restored habitats is a ubiquitous global problem and one of the greatest threats to biodiversity (Zedler and Kercher 2004). While many invaders spread rapidly, the causes of their expansion are rarely tested and reasons why some proceed to form monotypes (displacing all native species) are unexplored. In the Midwestern United States, monotypes of reed canary grass [*Phalaris arundinacea* L.] develop in wetlands that receive chronic inflows of runoff from agriculture activities and urban development. Over 40,000 ha of Wisconsin wetlands are now dominated by this species (Bernthal and Willis 2004).

Field studies. Once invaded by *Phalaris*, wet meadows retain few species. In our field sampling we found up to 60 species in little-disturbed reference sedge meadows (Kercher et al. 2004). In sedge meadows that had indicators of hydrological disturbance (culverts, drainage ditches, sediment plumes), however, we found up to 15 fewer species than in nearby undisturbed areas (Fig. 6). Furthermore, the species lost tended to be the more rare, specialized species that Wisconsin botanists have classified as "high quality" (Fig. 6; Kercher 2003). Our field sampling procedures were tested in detail, resulting in a publication that compared methods (Kercher et al. 2003).

Mesocosm experiment. We uncovered the mechanisms by which this widespread invasive clonal grass spreads and forms a monotype by comparing the responses of 17 taxa to four hydroperiods

(Kercher and Zedler in press) and by testing the effects of three components of runoff (excess water, nutrients, and sediments, alone and in combination) on *Phalaris* seedlings introduced to wet prairie vegetation in 140 replicate 1.1-m^2 mesocosms (Kercher 2003, Kercher and Zedler 2004). In pot microcosms, *Phalaris* and another invasive plant (the hybrid *Typha x glauca)* outperformed all native taxa in all hydroperiods. In the mesocosms planted to native species, the invasion process was reenacted as some treatments shifted the diverse wet prairie to a near-monotype of *Phalaris* in just two growing seasons (Fig. 7). Two mechanisms explained the conversion: (1) loss of natives due to prolonged flooding and sedimentation, and (2) superior growth of *Phalaris* with prolonged flooding, nutrient additions and sediment additions interacting to increase the invader's biomass (Kercher and Zedler 2004).

Resident species responded favorably to nutrient addition by producing more aboveground biomass, but resident species richness and biomass declined with prolonged flooding and addition of sediments in year 1, as more light became available and the community became invasible. Abrupt declines in resident species richness occurred in the first 6 weeks of the experiment, primarily due to prolonged flooding. Additional declines (1-2 species) were detected in year 2 for 7 of the 9 treatments with constant flooding. The effects of nutrients, sediments, and prolonged flooding were significant in year 1 and even stronger in year 2. In year 1, *Phalaris* aboveground biomass was 256 g per mesocosm in the high nutrients/constant flood treatment and, in year 2, 1728 g per mesocosm in the treatment with high nutrient level, topsoil sediment additions, and constant flooding. The biomass ratio of *Phalaris* to resident species increased significantly from a grand mean of 0.49 in year 1 to 1.64 in year 2. Near-monotypes were attained in 3 and 11 of the 28 treatments in year 1 and year 2, respectively. *Phalaris* increased over time in all but the no-treatment control (where biomass actually declined from 3.5 g in year 1 to 1.0 in year 2. Year 1 data appear in Kercher and Zedler (2004).

Our mesocosm study is unique in documenting significant interactions among disturbance factors on invasion by *Phalaris*. *Phalaris* biomass showed significant interactions for nutrient x flood regime and sediment x flood regime in year 2 (Fig. 7). The addition of sediments or nutrients combined with early season or constant flooding amplified invasion 30-130 % above expected (additive) levels!

Other results of our wetland research component have a more direct linkage to our social research component on the property owner acceptance of rain gardens to increase infiltration. In our outdoor mesocosm experiments, we identified four native plant species that are likely to grow well in bioretention areas including rain gardens because of their rapid biomass production and their ability to tolerate periods of both flooding and dryness: *Carex stricta*, *Calamagrostis canadensis*, *Spartina pectinata*, and *Eupatorium perfoliatium*. We also identified other species that were least suitable for rain gardens due to slow growth and inability to tolerate flooding.

Conceptual model. We developed a conceptual model that indicates how nutrient-rich runoff from either urban or rural landscapes accelerates invasibility at the landscape scale (Fig. 8). Because wetlands function as landscape sinks, they are vulnerable to influxes that create opportunities for invasion. When flooding brings opportunist species to the low-lying sites, invasive species take advantage of the opportunities to establish new plants. Then, ample nutrients and moisture accelerate growth of the established invaders. Given continued influxes of water and nutrients, aggressive invaders crowd out natives and form monotypes (Zedler and Kercher 2004). As depicted at the micro-scale (Fig. 9), the influx of water and sediment alters the sedge meadow wetland system and the tussocks that support other plant species. Infilling between the tussocks eliminates microtopography and provides a nutrient-rich substrate with little light limitation. Hence, colonization and dominance by reed canary grass can occur rapidly.

Summary. Thus our key ecological study component is linked to the physical attributes of our area's hydrologic system. To maintain the ecological health and biodiversity of natural wetland systems throughout the region, natural infiltration rates without an increase in runoff and associated nutrients and sediments must be maintained as an area urbanizes. Complex synergistic effects suggest that simple reductions in fertilizer use, flooding, or sedimentation alone will not suffice to protect wetlands from being overtaken by *Phalaris*. We suggest a holistic approach to controlling this invasive plant, including (1) minimizing runoff from agricultural fields and urban hardscapes (using depressions, swales, and other infiltration-enhancing measures); (2) removal of *Phalaris* (likely requiring herbicide and/or removal of sod); (3) replanting of natives; (4) long-term surveillance and spot-treating of re-invading clones; and (5) reintroducing native species that do not recover on their own. A long-term commitment will be required to restore biodiversity to wetlands degraded by *Phalaris*.

Thermal impacts of urban BMPs

Increased water temperature is an often overlooked water quality concern for urban best management practices (BMPs). This subproject examined three urban BMPs (0.43-ha wet detention pond, 0.10-ha bioengineered wetland, 26-m long grass swale) and quantified their impact on the thermal regime of runoff water. Water temperature and flow at the inlet and outlet of each BMP were monitored during 4-5 summer runoff events. Using these data, heat budgets were developed for each event with heat change calculated relative to rainfall (air) temperature.

Of the three BMPs, the wet pond contributed the greatest amount of additional heat to the water, resulting in an average volume-weighted heat increase of 20%. This heat was from previously stored water, which was displaced during a subsequent storm. The wetland complex increased the heat output of runoff water by an average of 10%. The smaller heat increase of the wetland was due to its smaller water storage capacity with less heat retained than in the pond. In contrast, runoff water passing over the grass swale actually lost heat (-43%). This loss was a result of water lost through infiltration and the complement of heat it contained, especially for the first flush of water off of hot impervious surfaces before they are cooled. Thus, innovative practices such as grass swales and rain gardens that infiltrate water can reduce thermal pollution from urban watersheds when compared to traditional stormwater practices such as detention ponds where thermal loading to receiving waters can be particularly significant.

Hydrologic Modeling

The overall goal of this project was to fill critical knowledge gaps and extend (or develop) analytical and modeling tools to minimize hydrologic impacts of urbanization. With respect to stormwater management, the primary emphasis was on small-scale infiltration practices, such as bioretention facilities and infiltration trenches. Except when soils or subsoils are impermeable, these practices can be used in urbanizing areas to prevent increases in the volume of storm runoff and decreases in the volume of groundwater recharge (Potter 2004). In this component of the research we developed numerical models that could be used to design and evaluate the benefits of small-scale infiltration practices. The models were developed for use at three spatial scales:

individual practice, development, and watershed. These models were then applied to provide insights about the design and use of small-scale infiltration practices.

Individual Infiltration Practices. We developed two models for simulating the performance of a multi-layered infiltration practice in continuous time. The first model uses the one-dimensional Richard's Equation to simulate flow through the infiltration practice. Application of this model to a 3-layered bioretention facility demonstrated three important points. First, if the purpose of the facility is to increase groundwater recharge, there is an optimal facility size. For the climate of southern Wisconsin, the optimal size is about 15% of the contributing impervious area. Second, an optimally designed bioretention facility can yield groundwater recharge rates well above rates that occur in undeveloped conditions. For example, an optimally designed bioretention facility in southern Wisconsin can more than double undeveloped recharge rates. This increase in recharge is due to the focusing of infiltration, which reduces losses to evapotranspiration. Third, an infiltration facility that is designed to maximize groundwater recharge can significantly reduce runoff volumes. These results are published in Dussaillant et al. (2003) and illustrated in Figure 10.

The long run times of our Richard's Equation model make it unsuitable for use in design. Hence we developed a much faster model based on the Green-Ampt equation. This model incorporates a user-friendly interface and allows the user to evaluate the performance of a multi-layered infiltration practice with an underdrain. We have also incorporated an algorithm that determines the facility size required to insure a specified volume of stormwater retention ("stayon"). This algorithm is being used by the State of Wisconsin to implement its new stormwater rules. We are also near completion of a technical manual for use in designing bioretention facilities.

Development Scale. We also recognized the need for a modeling approach for estimating the benefits of infiltration practices at the development scale. To meet this need we developed a spreadsheet model based on the commonly used NRCS "curve number" method, augmented to account for infiltration practices. We used our spreadsheet model to assess the potential benefits of infiltration practices in the context of four alternative development types: conventional curvilinear, urban cluster, coving, and new urbanism. Model results, published in Brander et al. (2004), indicate that urban cluster developments produce the smallest volume of runoff due to the large portion of land kept in a natural condition, and that significant reductions in runoff can be achieved in all four development types if infiltration practices are used to treat many impervious surfaces.

Watershed Scale. To model infiltration practices at the watershed scale we modified the USGS Precipitation Modeling system (PRMS). PRMS (Leavesley et al., 1996) is a modular design, distributed parameter, continuous rainfall-runoff model. Modifications included changing the model to allow for water to be directed from impervious areas to infiltration practices and modifying the infiltration algorithm to include ponding.

We applied the modified model to the North Fork of the Pheasant Branch watershed, a 50-km2 watershed in southern Wisconsin that had been previously modeled by Steuer and Hunt (2001) for existing conditions and two hypothetical urbanization scenarios. We considered two levels of infiltration practices, one moderate and one high. The results indicate that intensive use of infiltration practices can preserve groundwater recharge rates under either development scenario, but can only preserve runoff volumes for the moderate development scenario.

Agricultural Nutrient Management at the Urban Fringe

Our work was conducted in the "urban fringe" of the Pheasant Branch watershed near Middleton, Wisconsin. In this area, farming operations compete for land with development pressures while continuing to increase the soil phosphorus (P) levels on their fields. These operations find themselves facing the two equally unattractive propositions of paying for manure to be hauled elsewhere, or over-applying manure to the point that hydrologically vulnerable and erosive fields become saturated with P. We observe that the latter is the more frequent choice.

In the first phase of our research, we set out to sample soils for the purpose of determining where soil P surpluses had accumulated. We obtained cooperation of animal feeding operations (AFOs) in the 2,500-hectare North Fork subwatershed of Pheasant Branch (Fig. 1). These operations amounted to an area of approximately 1,300 hectares at a sampling density of approximately one sample per hectare on over 220 fields. Samples were analyzed for P using an agronomic test recommended for Wisconsin soils (Bray-P1). Figure 11 shows the extent of the sampling and a spatial interpolation of the soil P levels along a graduated scale that is commonly used in off-site P migration risk assessments. Our findings indicate soil P surpluses had accumulated at "sub-field" and field scales. In the case of a few operations, the majority of fields managed were saturated with excessive soil P levels.

The next phase consisted of interviewing the dairy producers who managed these fields, in order to understand if management decisions had resulted in the soil P surpluses indicated in Figure 11. Patterns of responses within the interviews were examined for decisions being made at the sub-field (operational), field (tactical), and farm (strategic) levels of farm management defined by Bouma et al. (1997) and Beegle et al. (2000).

In regards to sub-field decisions, it was evident that a great deal of variability existed indicating producers found it very hard to make precise management decisions. The most noteworthy point they made was the clear preference to haul only *full* loads of manure to their fields. Rather than hauling partial loads to a field to provide uniform coverage, producers reported that they would rather over-apply manure to portions of their fields, rather than returning from the field with the manure spreader still half-full.

At the field level of management, the first and most prevalent example of this is related to the tenure relationships of the producers to the fields under their management. It was common for most of the producers interviewed to develop informal and formal arrangements with other producers and local area landowners to rent land for crop production. However, many of these rented parcels were not available to producers from season to season, due to unstable rental arrangements brought on by competition with developers for rented parcels. This resulted in a dynamic land base that expanded or contracted annually. The ratio of owned-to-operated land was rather large for the small and mid-sized producers (>0.75), but was much smaller for the larger operations (<0.50). This limitation made some producers reluctant to develop and implement a nutrient management plan.

Finally, we examined the constraints faced by AFOs that manage manure in an urbanizing setting by sending a structured questionnaire to 186 farmers in a 212-km^2 area within the Lake Mendota watershed. The urbanizing setting was found to pose specific constraints on decisions at the farm level of management. For instance, producers cited that urbanization pressures had resulted in a fragmented pattern of land ownership and rental. This urbanizing context caused greater field separation and resulted in the need to haul manure greater distances on local roads (Cabot et al. 2004). The results of the survey indicated that producers were significantly more likely to encounter several situations (e.g., weekend traffic on local roads, complaints about spilled manure on public roads, springtime weight restrictions on local roads, traffic passing the hauler under unsafe conditions) as problematic if they were placing manure on fields located near home residences. In non-urbanizing watersheds, these problems do not constrain their decision making in regards to manure management. Because of traffic problems in an urbanizing setting, the likelihood increased for producers to repeatedly place manure on closer fields, which in turn can result in P surpluses.

Management implications. A popular strategy for helping dairy and livestock producers manage manure to meet agronomic and environmental goals in land-constrained areas and on fields where P surpluses have developed is to encourage cooperative agreements between producers and cash-grain farmers. Although cash-grain farmers have some concerns about receiving manure, when possible these agreements can alleviate nutrient surpluses that develop on land where manure is over-applied. However, an urbanizing setting presents a problem for the feasibility of these arrangements. Within the maximum distance that producers can profitably haul manure, tracts of cash grain land tend to be sparse already. When producers compete for these tracts with developers, their situation becomes even more constrained. Another strategy that could be useful in helping AFOs manage manure within a dwindling land base is to encourage manure brokering programs that direct manure to lands that can accept them. Finally, precision conservation (Berry *et al.* 2003) may also make it possible for producers to manage manure and nutrients at scales closer to the ones at which nonpoint source pollution originates. The hope of precision conservation is that producers will use geographic positioning systems (GPS) mounted to their equipment to avoid applying manure to hydrologically active zones or areas of elevated soil P accumulation. However, precision conservation is fairly costly and unfamiliar to most producers. Our current research efforts are aimed at making this technology more accessible.

Social Research – Impediments to Low Impact Development

Two areas of our social research relate directly to the barriers or impediments that must be overcome if low impact development is to be adopted as the norm in urban design. The first set of barriers can be classified as institutional, such as municipal ordinances that restrict any new development to environmentally unfriendly standard practices. The second set of barriers can be generally grouped in the realm of human biases and/or inadequate knowledge by key players. Each set of barriers were assessed separately as part of our project's research goals.

Institutional barriers. Land development patterns on the urban fringe are strongly influenced by local subdivision and zoning ordinances. Zoning regulations are established to control the use of property, whereas subdivision regulations address site planning and design. Subdivision ordinances are critical tools for guiding and influencing development attributes such as lot size, building setbacks, street configuration and street width.

Often, a subdivision ordinance is a rural community's only tool available to influence its physical development and mitigate potentially harmful land development impacts. Subdivision regulations have the most influence on development patterns at the site scale because they establish the procedures and standards that one must follow when dividing a large parcel of land in preparation for development.

Dane County (the location of our research study) was the fastest growing county in Wisconsin between 1990 and 2000, with the population increasing from 367,085 to 426,526 (U.S. Census 2000). Approximately 25,500 building permits were issued in the county between 1990 and 2000. About half of the permits were for multi-family dwelling units and half for single-family dwelling units (U.S. Census 2000). In recent years, more single-family dwellings have been constructed in the outlying urban service areas. In addition, the average size of new housing units has also increased (Dane County Regional Planning Commission 2001).

Dane County has 60 minor civil divisions (towns, villages and small cities exclusive of Madison). To assess the local regulatory standards for land development, we conducted a content analysis of all 60 subdivision ordinances. Also, a random 20% sample of subdivision plats was taken from each of the minor civil divisions with more than five subdivisions platted during the 1990s. This yielded a sample of 75 subdivisions for assessing current practices.

Our study found that 97% of sampled subdivisions in Dane County were "conventional" subdivisions, which are characterized by large lots, wide streets, curb and gutter, and detention basins. Only 3% were "Traditional Neighborhood Developments" or "conservation" subdivisions, which are characterized by clustered small lots, narrow streets, and common open spaces. The average area of each subdivision was 32 acres (12.6 ha) with an average of 48.6 lots in each subdivision. There was very little evidence of "best management practices" to ensure low-impact residential development. The vast majority of the subdivisions included large, connected impervious surfaces (e.g., streets with required curbs and gutters; cul de sacs with a required pavement diameter of 110 feet) that reduce stormwater infiltration and increase runoff. Most of the subdivisions also utilized a "pipe and pond" approach to stormwater management, further diminishing on-site infiltration and recharge. In summary, Dane County's subdivision regulations generally encouraged, and in some instances mandated, "high-impact" development practices.

Barriers from human biases or inadequate knowledge. Many of the environmentally unfriendly ordinances discussed above embody the interests and views of various institutional players (e.g., fire department and snow removal personnel). Their reluctance to change reflects the deeper problem that municipal officials (e.g., planners, engineers) and citizen oversight committees in general have little experience with low impact development designs pertaining to water management.

In-depth personal interviews conducted with a wide range of individuals (e.g., municipal officials, regional planners, builders, developers, engineers, and environmental consultants) instrumental in the adoption of alternative storm water management practices elucidated this problem further. These interviews disclosed that the adoption of even a single, simple practice such as a rain garden is a potentially complex event. A large number of actors and considerations are important including cost, the physical, institutional and legal environments, and the understanding of various key actors (engineers, builders, developers). Interestingly, homeowners and renters are of scant importance in driving the decision to install these practices in new developments. Decisions on these matters are made early in the development phase when owners/tenants have little input or impact.

Another finding of our sociological research is a key barrier to the adoption of infiltration practices: the lack of knowledge about the practices and their effectiveness under different conditions. Conventional storm water management practices are well understood; their alternatives are not. Builders, developers, planners, regulators and municipal officials need to know how these practices can be installed, how well they function in different settings, and what they cost to install and maintain. Additional research and documentation of the practices can overcome this barrier. In particular, a high priority to funding and implementing demonstration projects of the low impact practices in a variety of settings is critical to their rapid acceptance.

Impediments for retrofitting existing urban areas. While the previous discussion addresses issues related to implementing low impact development practices in areas undergoing urbanization, different problems exist for retrofitting these practices in established urban areas. Other than larger-scale infiltration systems installed on public lands, individual homeowners and commercial property owners are the key players for implementing rain gardens or other infiltration systems at the scale of individual properties.

Through the use of focus group listening sessions conducted in May 2002, we were able to document how residents of Maplewood, Minnesota accepted the voluntary installation of rain gardens as part of larger municipal projects to alleviate chronic flooding problems in their community. In general, homeowner "gardeners" tended to be younger, liked gardening in general, and often had experienced water problems on their property, as compared to "non-gardeners." Voluntary sign-up brought a greater sense of buy-in and prevented unwilling homeowners from having to plant and maintain gardens that were perceived as requiring too much care. Participants found the ideas of "helping your neighbor" and getting rid of standing water that was disproportionately affecting some in their neighborhood as more persuasive reasons for participating than broader appeals for beautifying the community and saving taxpayer costs for managing storm water in the larger watershed. Because few homeowners had any prior knowledge of rain gardens, they had not developed specific attitudes towards rain gardens other than the word "garden" has the connotation of "work." The common mode of reasoning against having a rain garden – "I don't have a water problem, so I don't need a garden" – must be overcome by educational programs. The value of well-organized rain garden demonstration projects is paramount to the infiltration practice's successful implementation by enough homeowners to make a difference in the watershed management of a community.

Policy implications for urbanizing areas. The Wisconsin Smart Growth Law requires all communities that want to make a land use decision to create and adopt a comprehensive plan by January 2010. The Smart Growth legislation also required all communities with a population of 12,500 or more to develop a Traditional Neighborhood Development ordinance by January 2002. Traditional Neighborhood Development ordinances encourage development of compact, transit oriented, pedestrian friendly, mixed-use, and sustainable neighborhoods. To reduce land development impacts, local subdivision ordinances should be examined, and revised if necessary. These ordinances should be consistent with the principles of smart growth. And they should promote – if not require low – impact development practices. Our project has identified ordinances that are barriers to low impact development and will be making recommendations to eliminate this set of barriers.

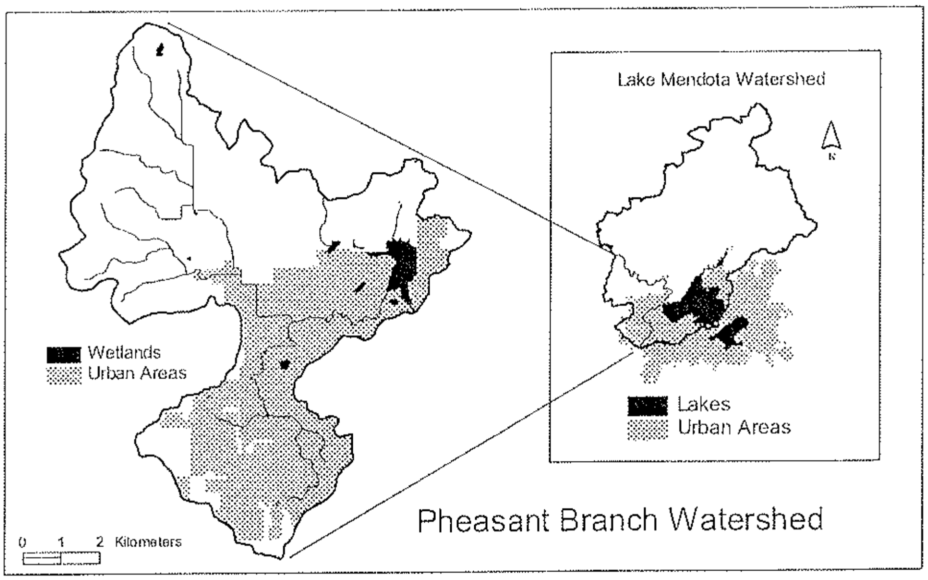

Fig. 1. Map of Lake Mendota watershed including Pheasant Branch subwatershed and Madison metropolitan urban area. The enlarged map of Pheasant Branch shows the major downstream wetland and the North Fork creek area that is still in agricultural land use (not shaded).

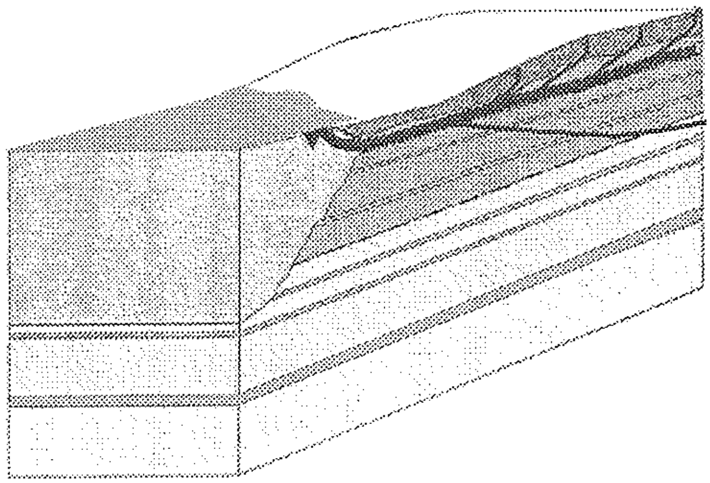

Fig. 2. Spring locations at the edge of wetlands are controlled by the hydrostratigraphy and paleotopography of the region. Groundwater in the upper aquifer is replenished by infiltration through glacial till. Groundwater moves through high permeability layers or preferential flow paths in the upper aquifer and exits as springs where these permeability layers are exposed along the edges of wetlands. A regional aquitard of shale (brown) separates the upper aquifer from the deeper bedrock aquifer.

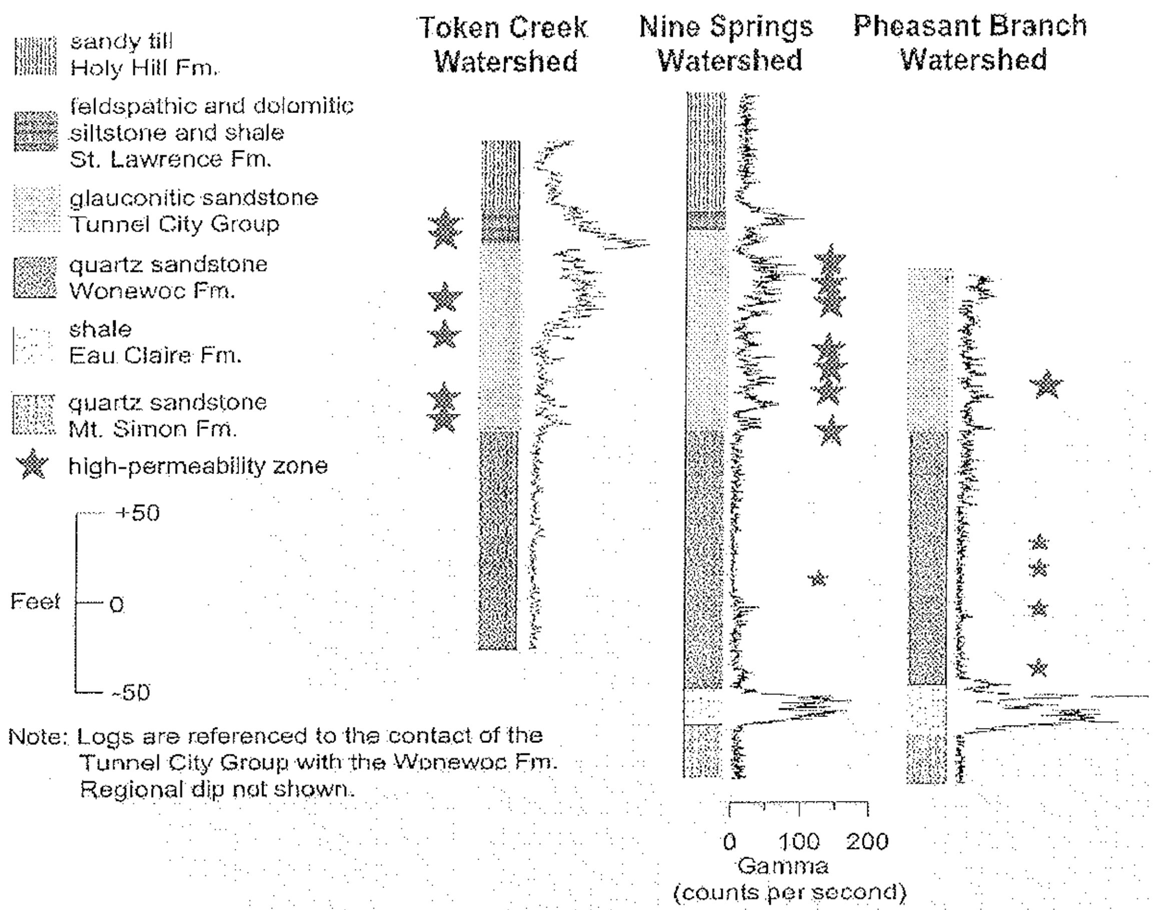

Fig. 3. Stratigraphy and high permeability zones in bedrock wells in three watersheds near Madison Wisconsin. High permeability zones are concentrated in the Tunnel City formation and some of these correlate between watersheds separated by tens of kilometers.

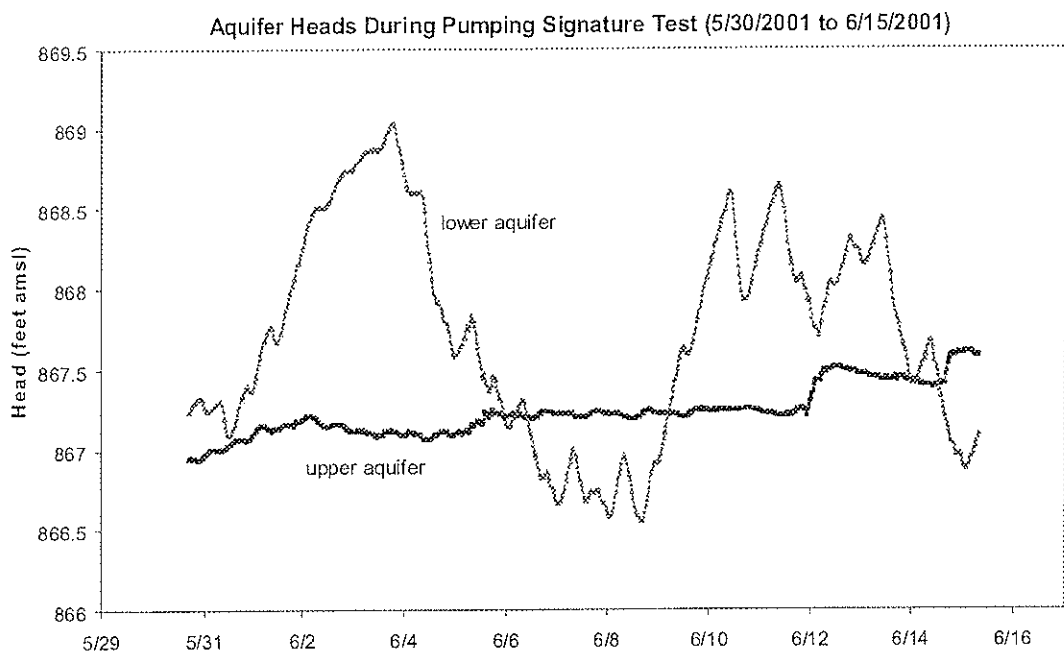

Fig. 4. Water levels (heads) of the upper and lower bedrock aquifers as monitored at well DN-1440 during a 16 day observation period in early summer 2001. Heads in the lower aquifer drop during periods of pumping and rise during periods when pumps are shut off. Heads in the upper aquifer show no response to pumping, but do show responses to rainfall (e.g. on 6/12). The vertical gradient across the shale was observed to reverse several times during the course of the municipal pumping signature test, indicating a potential for downward flow during pumping and upward flow when pumps are shut off. Flow in the nearby Frederick Springs shows no detectable variation related to these pumping cycles.

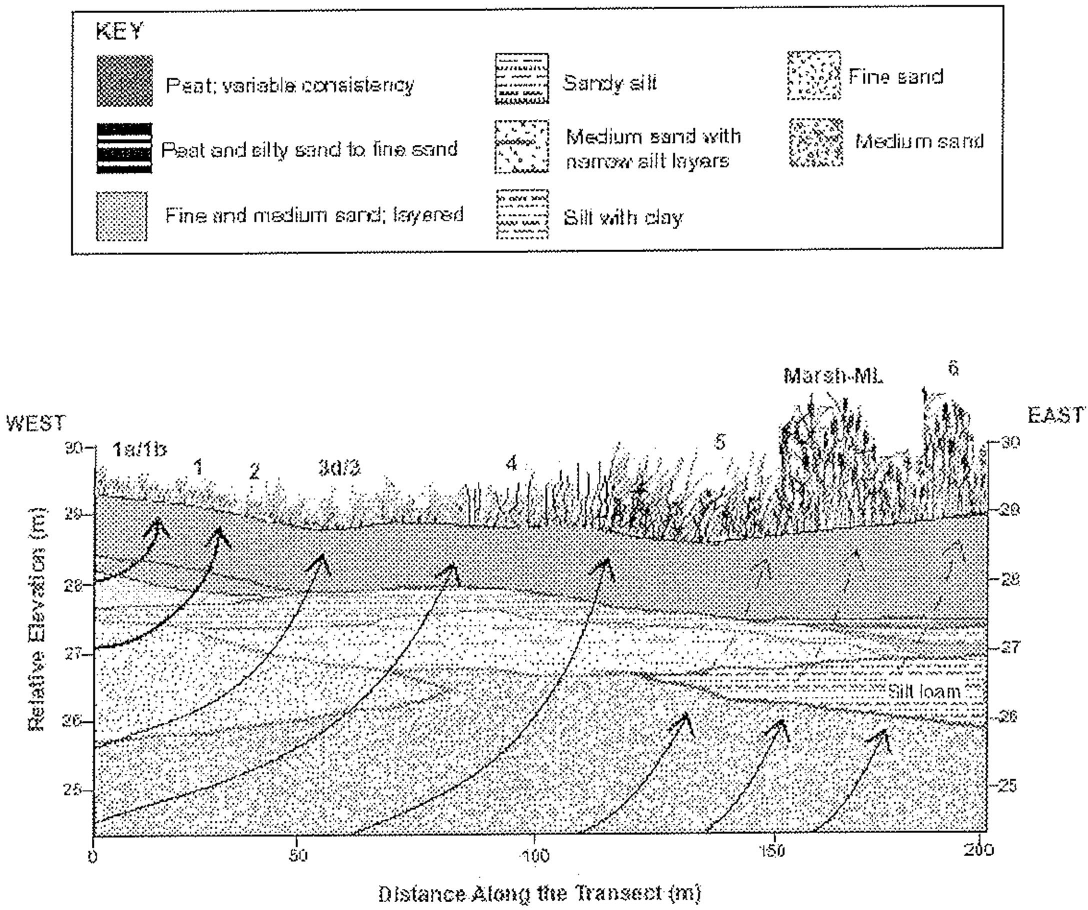

Fig. 5. Conceptual model of Cherokee Marsh wetland transect illustrating the interaction between stratigraphy, groundwater discharge, and vegetation gradients. The fen is located at the western end of the transect, the sedge meadow in the center and the marsh at the east. Groundwater discharge, represented by arrows, decreases from 0.0039 m/day in the fen to 0.0016 m/day in the marsh.

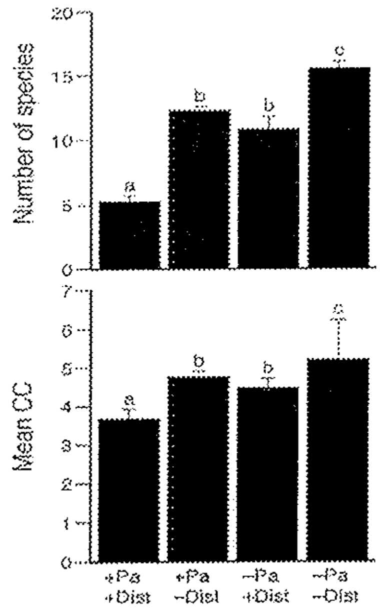

Fig. 6. Species richness and mean coefficients of community (CC, a measure of species "quality") in Dane County, Wisconsin, wetlands with and without indicators of hydrological disturbance (± Dist). Phalaris arundinacea *(reed canary grass) was found in some sample plots and not others (±* Pa*). Both species richness and CC were lowest when* Phalaris *was present in areas with indicators of hydrological disturbance, such as culverts and drainage ditches.*

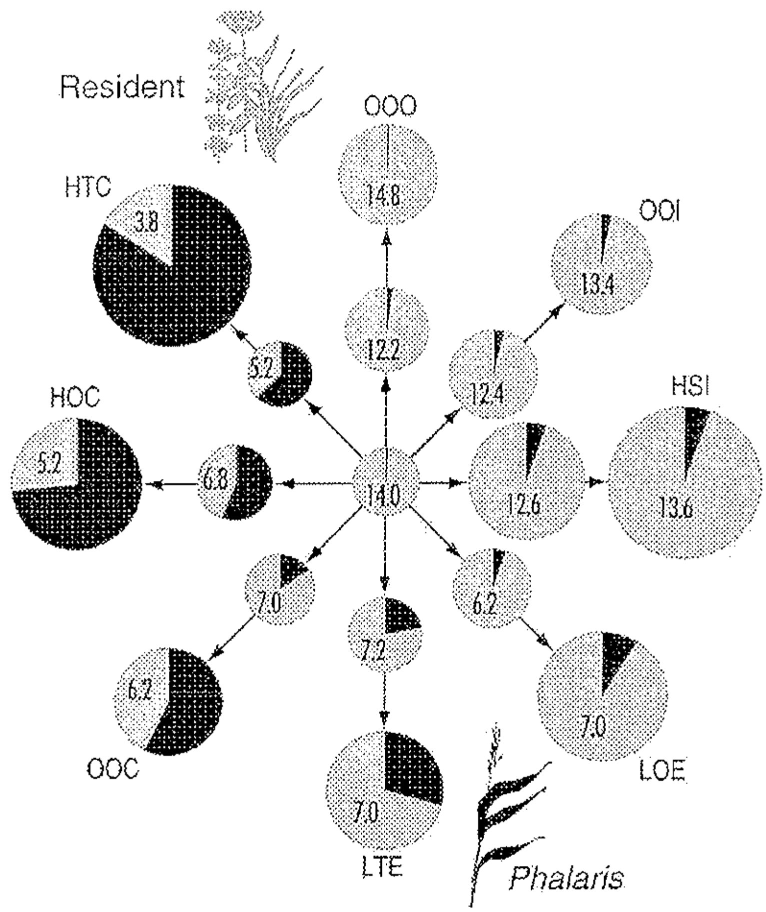

Fig. 7. Responses of Phalaris arundinacea *(reed canary grass) in black and resident species (forbs, grasses and graminoids of Wisconsin wet prairies) in green to a selection of nutrient, sediment, and flooding treatments (000 = control with no treatment in the 3 respective categories; Nutrient addition = 0, Low, Medium, High; Sediment addition = 0, Sand, Topsoil; Flooding = Intermittent, Early, Constant) in a replicated 1.1-m² mesocosm experiment. Starting conditions are shown in the middle pie, with 14 species planted in all mesocosms and moderate biomass dominated by residents. The first ring of pies shows year-1 results, and the second ring shows year-2 results, with plant standing crops equal to circle area. Seven of the 27 treatments are depicted, for comparison with the control, aligned clockwise in order of increasing* Phalaris *contribution to biomass. Note that as* Phalaris *biomass increases, the number of species drops to as low as 3.8 per mesocosm in the treatments with high nutrients, topsoil addition, and constant flooding.*

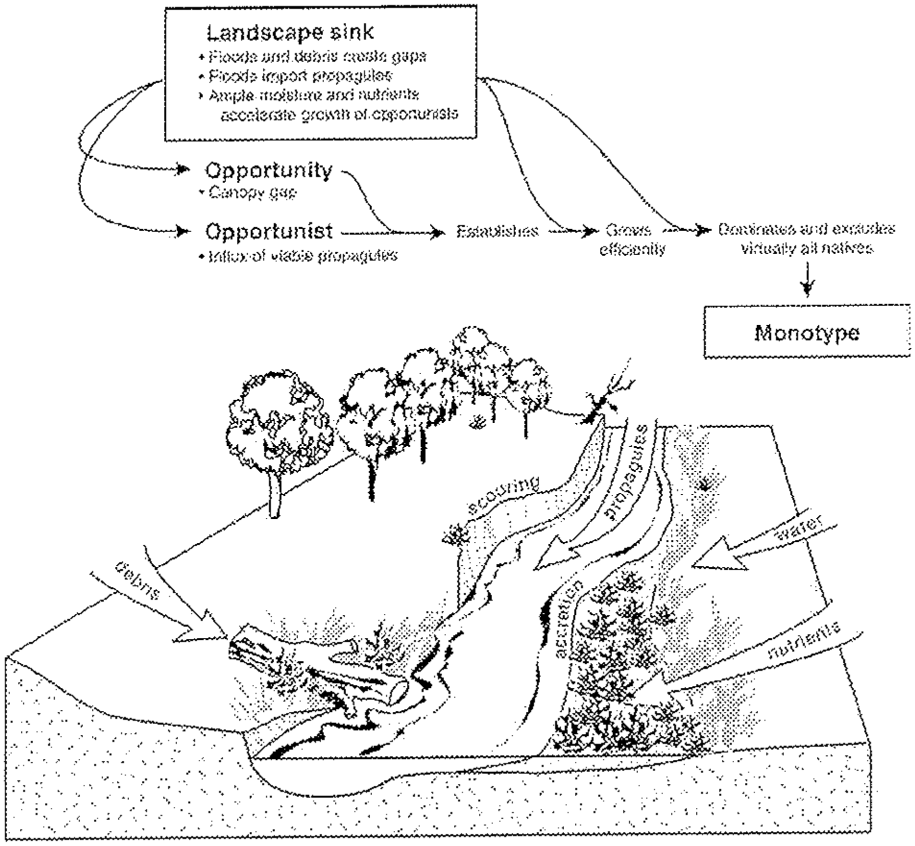

Fig. 8. Conceptual model explaining how opportunistic invasive species become established in wetlands. Gaps in wetland resident plant canopies are created by debris and scouring, and floodwaters bring propagules (seeds, plant fragments) of invasive species to the gaps. Once the invaders establish, flood waters and nutrients enhance their growth and vegetative spread, often forming monotypes.

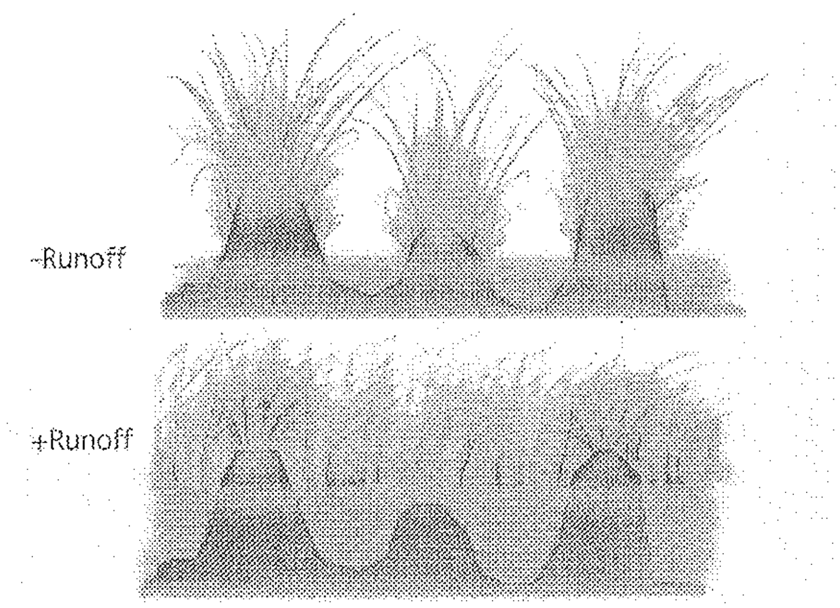

Fig. 9. Illustration of native sedge meadows (labeled "-Runoff" to indicate a lack of urban and agricultural runoff), which have complex tussocks that support high species richness, and wetlands altered by sediment- and nutrient-rich runoff (labeled "+Runoff"), which lose their native species and become dominated by aggressive reed canary grass, Phalaris arundinacea. The "+Runoff" graphic depicts tussocks partly or completed covered with runoff water and deposited sediments.

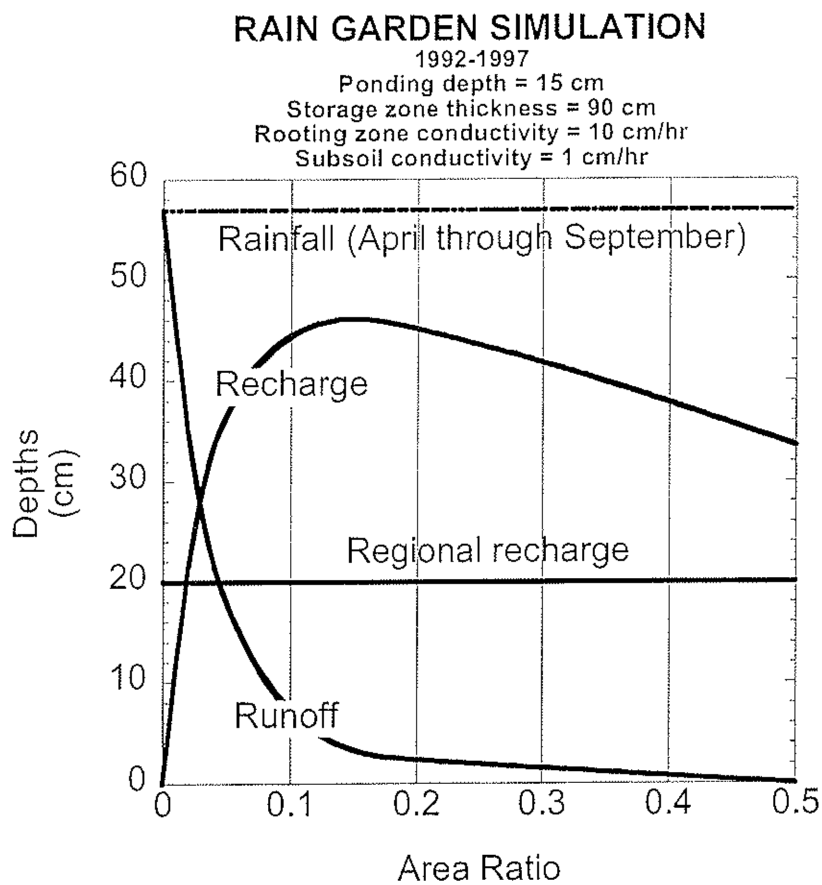

Fig. 10. Simulation results for total area averaged (impervious and pervious) recharge and runoff for Madison 1992-1997 rainy seasons.

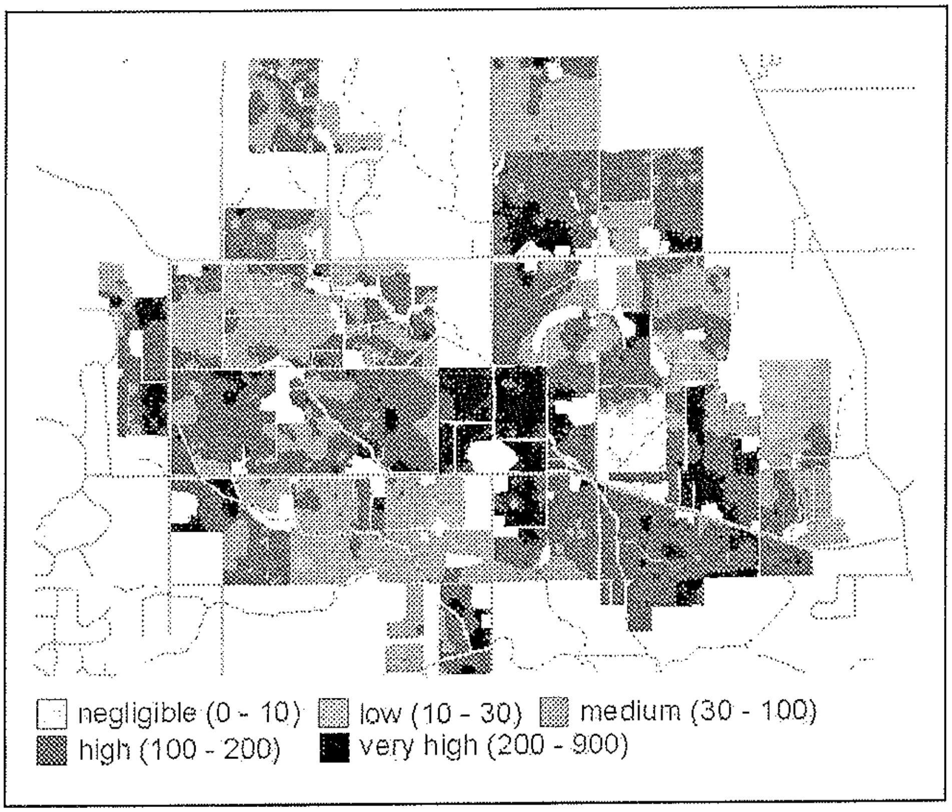

Fig. 11. Soil test P levels (Bray-P1, ppm) in the North Fork of the Pheasant Branch study area.

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Appendix 4

G.F. Birch, M.S. Fazeli, and C. Matthai
Environmental Monitoring and Assessment (2005):
Efficiency of an Infiltration Basin in Removing
Contaminants from Urban Stormwater

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EFFICIENCY OF AN INFILTRATION BASIN IN REMOVING CONTAMINANTS FROM URBAN STORMWATER

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Abstract. The efficiency of a Stormwater Infiltration Basin (SIB) to remove contaminants from urban stormwater was assessed in the current investigation. The SIB, installed in an urban suburb in eastern Sydney (Australia), was monitored over seven rainfall events to assess the removal efficiency of the remedial device for total suspended solids (TSS), nutrients (TP, TKN, N_{ox}, TN), trace metals (Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn), organochlorine pesticides and faecal coliforms (FC) from stormwater. The weighted average concentration (WAC) of TSS in the stormwater effluent from the SIB was reduced by an average of 50%, whereas the WAC of Cu, Pb and Zn were also reduced by an average 68%, 93% and 52%, respectively. However, the WAC of Cr, Fe, Mn and Ni displays either similar concentrations as the stormwater influent (Cr and Mn), or substantially higher concentrations (Fe and Ni), due possibly to leaching of fine-grained zeolite clay particles in the filtration bed. The mean removal efficiency of the SIB for total phosphorus (TP) and total Kjeldahl nitrogen (TKN) was 51% and 65%, respectively. In contrast, the average WAC of oxidisable nitrogen (nitrate and nitrite nitrogen or N_{ox}) is about 2.5 times greater in the effluent (1.34 ± 0.69 mg L^{-1}) than in the incoming stormwater (0.62 ± 0.25 mg L^{-1}). The WAC of total nitrogen (TN) was similar for stormwater at the in-flow and out-flow points. The SIB was very efficient in removing FC from stormwater; and the WAC of almost 70 000 cfu $(100\ \mathrm{mL})^{-1}$ at inflow was reduced to <2000 cfu $(100\ \mathrm{Ml})^{-1}$ at the outflow, representing a mean removal efficiency of 96%. Due to the low concentrations of Cd, organochlorine pesticides and PAHs in the stormwater, it was not possible to assess the efficiency of the SIB in removing these contaminants.

Keywords: infiltration basin, stormwater, contaminants, remediation

1. Introduction

Stormwater runoff often contains organic and inorganic contaminants, nutrients and faecal coliforms (FC) that are associated with suspended solids and the dissolved-phase (Lee *et al.*, 2002; Walker *et al.*, 1999; Sansalone, 1999). Stormwater may transport high concentrations of these toxicants, including gross pollutants, into adjacent receiving waters (rivers, lakes, estuaries and sea/ocean) resulting in degraded water and sediment quality. To protect an aquatic ecosystem from stormwater pollutants, a treatment system must adsorb dissolved elements and filter particulate-bound fractions (Weiss *et al.*, 2002; Sansalone, 1999; Sansalone and Buchberger, 1995). A variety of passive, *in-situ* treatment systems have been considered for drainage from urban areas and pavements in Australia and other developed countries

(Matthia 2000; Ellis, 2000; Sansalone, 1999). The degraded nature of many receiving waterways has generated increasing interest in stormwater *in-situ* treatment infiltration basins, to remediate urban and pavement drainage (Sansalone, 1999; Ferguson, 1995). State and local government authorities in Australia are undertaking major public awareness campaigns in an attempt to improve stormwater quality.

The Stormwater Infiltration Basin (SIB) tested in the current study is located in a small urban park in eastern metropolitan Sydney (Annandale). The total area of the SIB and associated infrastructure is approximately 450 m^2 and the catchment area to the site is 2.668 ha (Martensand Associates, 1998). The catchment drains an urban area with terrace houses, streetscapes and parklands.

2. Materials and Methods

The SIB was designed to cater for a 1 in 2 yr 1 h (40 mm) rainfall runoff event, providing a design runoff volume for treatment (per event) of approximately 1 mL (Martens and Associates, 1998). The inflowing stormwater enters the SIB via a rectangular channel (width: 35 cm; height: 20 cm), covering the entire length of the basin. The length of the SIB is 31 m and the width is between 11 m and 16 m. The SIB is contained by low-permeability grassed earthen bunds and the stormwater treatment occurs by infiltration through the surface of the SIB and flow through the filtration media consisting of a 1:6 mixture of zeolite and coarse, pure quartzitic sand with a mean diameter of 2 mm. The zeolite is a natural, predominantly Ca/Mg clinoptilolite, with minor mordenite and a cation exchange capacity of 550 meq kg^{-1}. The maximum centre depth of the SIB is 1.5 m. The treated stormwater is collected by a centrally located collection drain, which transports effluent to an existing 40 cm diameter stormwater pipe, leading into a nearby creek (Whites Creek).

Stormwater samples were collected at the SIB between October and December, 1999. During this period, nine events were sampled (Events A–I) using Sigma 900 MAX autosamplers, which were deployed at the inflow and outflow of SIB. The stormwater samples were collected via 3/8 inch inner diameter teflon-coated sample tubing and delivered directly into the 1000 mL acid-washed polyethylene sample bottles in order to minimise contamination. Rainfall for the initial 24-h period of each event was between 1.5 mm and 49 mm. The infiltration time of stormwater runoff into the SIB was estimated by the time difference between the rise in water level at the inflow and outflow sampling points.

A trash rack (dimensions: 60 cm × 50 cm × 100 cm) was located upstream of the inflow sampling point and the volume of litter captured by this device was estimated visually after each rainfall event. Discrete sampling rather than composite sampling was employed, with 6 to 8 samples of the total of 24 samples being selected for analysis following the inspection of the hydrograph data. Two samples were collected from the rising and falling limbs of the hydrograph and the peak flow, respectively.

The first two rainfall events (Events A and B) were used to calibrate the sampling and monitoring system for high-precipitation events. The characterisation of subsequent flood events (Events C–H) included the determination of concentrations of total suspended solids (TSS) (all Events), trace metals (Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn) (all Events), nutrients (TKN, NO_x, TP) (Events E–H) and FC (Events E–H) in the inflowing and outflowing stormwater. A single rainfall event (Event I) was sampled to determine the concentrations of organochlorine pesticides (OCs), polycyclic aromatic hydrocarbons (PAHs), total oil and grease, nutrients and trace metals.

The event-mean concentration is the weighted average concentration (WAC) of a parameter measured in stormwater samples (e.g., TKN, TP, Cu, TSS) over the sampling period (i.e., the time between the collection of the first and the last sample). The sum of the average concentrations for each interval of known duration was divided by the total sampling interval to obtain the WAC of the parameter for the storm event. The WAC of the event was calculated for each of the inflow and outflow points. The removal efficiency of the stormwater remedial device was estimated by:

$$RE = WAC_{inflow}/WAC_{outflow} \times 100\%,$$

where RE is the removal efficiency (in %); WAC_{inflow} is the weighted average concentration at the inflow point; and $WAC_{outflow}$ is the weighted average concentration at the outflow point (Figure 1).The total load of a parameter measured in the stormwater samples (e.g., TKN) which was discharged during a storm event was estimated by multiplication of the WAC with the volume of stormwater discharged during the event.

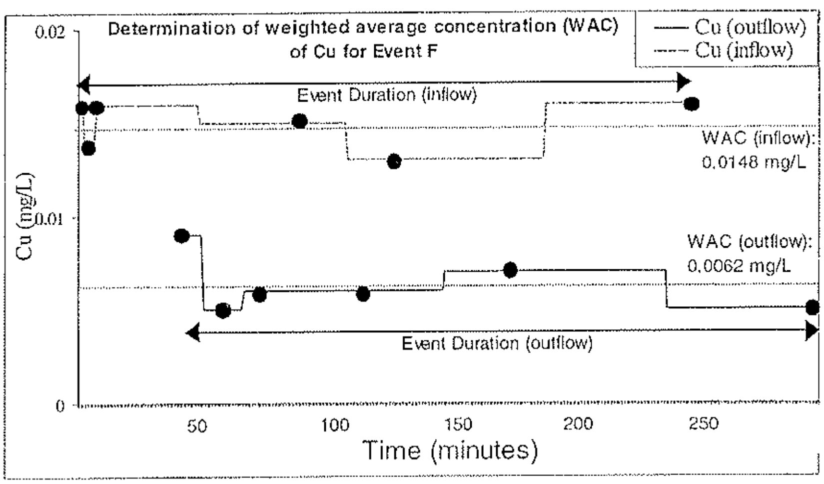

Figure 1. Estimation of weighted average concentration (WAC) during a high flow event, using the different concentrations of Cu observed during Event F as an example.

TABLE I

Analytical methods, minimum sample volumes required for analyses and analytical detection limits

Analysis	Minimum volume required (ml)	Detection limit (mg/L)	Method reference
NO_x	20	0.01	APHA 4500
TKN	200	0.05	APHA 4500
TP	50	0.05	USEPA 200. 7,8 by ICP
Faecal coliforms	120	–	APHA 9222D
Trace metals (Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn)	100	0.001–0.020	USEPA 200.7,8 by ICP
Organochlorines and PCBs	400	0.01–0.1 mg/L	USEPA 8081 by GC-ECD
PAHs + 2-methylnaphthalene	400	0.001–0.002	USEPA 8270mod by GC
Oil and grease	500	5	APHA 5520D

All chemical sample analyses were performed by a National Association of Testing Authorities (NATA) accredited laboratory (Australian Government Analytical Laboratories, Sydney, AGAL). Minimum sample volumes required for analysis range between 20 mL for NO_x and 500 mL for total oils and greases. Detection limits and method references are given in Table I.

For Quality Control/Quality Assurance, all analytical work on samples from Events C to I and LA at the SIB, meets strict NATA accreditation requirements (Table II). Analytical blanks were below detection limits for all parameters, eliminating the possibility of laboratory contamination. Relative standard deviations of repeat analyses of samples were below 10%, except for four parameters (Cr: 20% RSD, Event E; P: 18% RSD, Event F; Fe: 12% RSD, Event I; TSS: 16.7% RSD, Event F). Spike recoveries of control blanks, matrix-matched standards and standard reference materials (SRM) were all within the acceptance criteria of the NATA accredited laboratory.

3. Results and Discussion

Stormwater sand filters have been shown to remove a high proportion (75–100%) of suspended solids from stormwater, although a pre-treatment for coarse sediment and litter removal is required (EPA, 1997). The estimated removal of total phosphorus (TP), nitrogen, oil and grease and bacteria by sand filters is moderate (50–75%

TABLE II

Quality control/quality assurance for analytical work on samples from Events C-I and LA at the SIB

Event	Elements	Detection limit (DL) (mg/L)	Blank	RSD (%)	Spike recoveries: Blank spike	Matrix	SRM
LA	Trace metals	0.001 (Fe: 0.005)	<DL	<2	86–108	85–103	–
C	Trace metals	0.001 (Fe: 0.005)	<DL	<10	78–115	93–108	–
D	Trace metals	0.001 (Fe: 0.005)	<DL	<8	86–108	83–110	–
E	Trace metals	0.001 (Fe: 0.005); P: 0.05)	<DL	<7.1 (Cr: 20%)	97–120	89–110	89–110
F	Trace metals	0.001 (Fe: 0.005)	<DL	<3 (P: 18%)	89–103	85–102	88–111
G	Trace metals	0.001 (Fe: 0.005)	<DL	<7	86–111	86–105	88–108
H	Trace metals	0.001 (Fe: 0.005)	<DL	<5	88–115	90–110	82–103
I	Trace metals	0.001 (Fe: 0.005)	<DL	<7 (Fe: 12%)	88–105	94–108	82–117
LA	TSS	2	<2	0	100	–	
	NO_x	0.01	<0.01	–	93	96	
	TKN	0.05	<0.05	–	108	99	
C	TSS	2	<2	0	93	–	
	NO_x	0.01	<0.01	–	–	–	
	TKN	0.05	<0.05	–	–	–	
D	TSS	2	<2	0	93	–	
	NO_x	0.01	<0.01	–	–	–	
	TKN	0.05	<0.05	–	–	–	
E	TSS	2	<2	2.4	93	–	
	NO_x	0.01	<0.01	2.6	102	80	
	TKN	0.05	<0.05	4.9	102	111	
F	TSS	2	<2	16.7	97	–	
	NO_x	0.01	<0.01	0	104	100	
	TKN	0.05	<0.05	2.1	104	99	
G	TSS	2	<2	0	95	–	
	NO_x	0.01	<0.01	2.1	105	102	
	TKN	0.05	<0.05	2.4	103	109	

(*Continued on next page*)

TABLE II
(*Continued*)

Event	Elements	Detection limit (DL) (mg/L)	Blank	RSD (%)	Spike Recoveries: Blank spike	Matrix	SRM
H	TSS	2	<2	–	–	–	
	NOx	0.01	<0.01	–	–	–	
	TKN	0.05	<0.05	–	–	–	
I	PAH	1	<1	–	–	96–119	
	OC pesticides	0.01	<0.01	–	–	92–116	
	TSS	2	<2	–	–	95	
	Oil and grease	5	<5	–	–	95	

Acceptance Criteria	Recovery (%)	RSD(%)
Nutrients	80–120	<20
Trace metals + TP	75–120	<37
PAHs, OC Pesticides	50–150	<40

removal), with the potential for pollutant remobilisation being low (10–50% removal) (EPA, 1997).

In the present study, the concentration of trace metals (Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn), nutrients (TP, TKN, N_{ox}, TN), TSS and FC in stormwater runoff (Events C–I) from inflow and outflow points at the SIB are presented in Table III and Figure 2, with WAC. In the current work, the mean removal efficiency of TSS by the SIB is about 50%, although the mean removal of suspended particulates for each of the seven events monitored was between 20% and 88%. The mean removal efficiencies of TP and total Kjeldahl nitrogen (TKN) are 51% and 65%, respectively, indicating a moderate removal efficiency of these stormwater contaminants by the sand filter. In contrast, the mean faecal coliform content of the stormwater was about 96%, lower at outflow compared to the inflow of the SIB, indicating that a high proportion of FC are removed from the stormwater by infiltration through the sand filter.

The mean removal efficiencies of Cu, Pb and Zn are also moderate to high, varying between 49% and 81% (mean: 68%), 88% and 98% (mean: 93%) and −1% and 77% (mean: 52%), respectively. However, the mean removal efficiencies of Cr, Fe, Mn and Ni were shown to be substantially more variable, with concentrations of these elements in the outflowing stormwater frequently exceeding the concentrations of the inflowing waters. In particular, the concentrations of Cr (mean removal efficiency: −29%), Fe (mean removal efficiency: −81%) and Ni (mean removal efficiency: −65%) display an increase in concentrations, following treatment by infiltration through the sand filter. Although no mineralogical analysis was conducted on the suspended particulates in the treated stormwater, it is likely that the increase

TABLE III

Weighted average concentrations (WAC) and removal of trace metals (Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn), nutrients (TP, TKN, N_{Ox}, TN), total suspended solids (TSS) and faecal coliforms (FC) in stormwater runoff (Events C–I) from inflow and outflow points at the SIB

Event		WAC (Cd)	WAC (Cr)	WAC (Cu)	WAC (Fe)	WAC (Pb)	WAC (Mn)	WAC (Ni)	WAC (Zn)
C	Inflow	bd	0.0017	0.037	0.15	0.030	0.028	0.0045	0.255
	Outflow	bd	0.0019	0.013	0.47	0.004	0.0192474	0.0060	0.121
	Removal efficiency (%)	–	−11	65	−213	88	32	−33	52
D	Inflow	bd	bd	0.019	0.19	0.030	0.029	0.0017	0.387
	Outflow	bd	bd	0.004	0.34	0.002	0.014	0.0025	0.147
	Removal efficiency (%)	–	–	81	−85	95	52	−45	62
E	Inflow	bd	0.0030	0.013	1.20	0.108	0.027	0.0024	0.194
	Outflow	bd	0.0052	0.007	3.17	0.011	0.073	0.072	0.197
	Removal efficiency (%)	–	−74	49	−165	90	−166	−202	−1
F	Inflow	bd	bd	0.015	0.22	0.21	0.18	0.0015	0.193
	Outflow	bd	0.0011	0.006	0.63	0.002	0.031	0.0047	0.084
	Removal efficiency (%)	–	–	58	−186	91	−78	−213	57
G	Inflow	bd	bd	0.021	0.22	0.029	0.031	0.0026	0.286
	Outflow	bd	bd	0.005	0.16	0.001	0.007	0.0021	0.095
	Removal efficiency (%)	–	–	78	29	98	78	19	67
H	Inflow	bd	0.0012	0.025	0.24	0.029	0.031	0.0029	0.393
	Outflow	bd	0.0017	0.006	0.21	0.001	0.010	0.00362	0.0091
	Removal efficiency (%)	–	−42	76	12	97	69	−9	77
I	Inflow	bd	0.0037	0.025[a]	2.16	0.042	0.072	0.0060	0.142[a]
	Outflow	bd	0.0033	0.023[a]	1.33	0.044[a]	0.044	0.0043	0.159[a]
	Removal efficiency (%)	–	10	8[a]	38	−5[a]	39	27	−12[a]
C–I	WAC (Inflow)	–	0.0024	0.022	0.63	0.041	0.034	0.0031	0.285
	SD (%)	–	0.0012	0.009	0.77	0.033	0.018	0.0016	0.089
	RSD (%)	–	49	40	124	80	52	52	31
C–I	WAC (Outflow)	–	0.0026	0.007	0.90	0.003	0.028	0.0043	0.122
	SD (%)	–	0.0017	0.003	1.07	0.004	0.024	0.0019	0.043
	RSD (%)	–	63	49	119	120	83	43	36

(*Continued on next page*)

TABLE III
(Continued)

Event		WAC (Cd)	WAC (Cr)	WAC (Cu)	WAC (Fe)	WAC (Pb)	WAC (Mn)	WAC (Ni)	WAC (Zn)
C–I	Mean removal efficiency (%)	–	−29	68	−81	93	4	−65	52
	SD of Removal efficiency (%)	–	26	13	108	4	91	101	28
C–I	n (number of events sampled	0	4	6	7	6	7	7	6

Event		WAC (TSS)	WAC (P)	WAC (FC)	WAC (TKN)	WAC (NOx)	WAC (TN)
C	Inflow	25	nd	nd	nd	nd	nd
	Outflow	20	nd	nd	nd	nd	nd
	Removal efficiency (%)	20	nd	nd	nd	nd	nd
D	Inflow	16	nd	nd	nd	nd	nd
	Outflow	10	nd	nd	nd	nd	nd
	Removal efficiency (%)	37	nd	nd	nd	nd	nd
E	Inflow	109	0.27	34495	0.54	0.26	0.80
	Outflow	37	0.17	3397	0.29	0.69	0.98
	Removal efficiency (%)	66	37	90	47	−166	−22
F	Inflow	26	0.26	70193	1.68	0.70	2.38
	Outflow	18	0.14	964	0.54	2.29	2.83
	Removal efficiency (%)	34	47	99	68	−229	−19
G	Inflow	17	0.20	54725	1.69	0.76	2.45
	Outflow	2	0.07	922	0.43	1.03	1.47
	Removal efficiency (%)	88	67	98	74	−36	40
H	Inflow	19	0.25	116162	2.16	0.78	2.94
	Outflow	5	0.11	1571	0.64	1.36	1.97
	Removal efficiency (%)	72	55	99	72	−74	33
I	Inflow	80	nd	nd	nd	nd	nd
	Outflow	55	nd	nd	nd	nd	nd
	Removal efficiency (%)	31	nd	nd	nd	nd	nd

(Continued on next page)

TABLE III
(Continued)

Event		WAC (Cd)	WAC (Cr)	WAC (Cu)	WAC (Fe)	WAC (Pb)	WAC (Mn)	WAC (Ni)	WAC (Zn)
C–I	WAC (Inflow)	42	0.25	68894	1.52	0.62	2.14		
	SD (%)	37	0.03	34737	0.69	0.25	0.93		
	RSD (%)	89	13	50	45	39	43		
C–I	WAC (Inflow)	21	0.12	1713	0.47	1.34	1.81		
	SD (%)	19	0.04	1161	0.14	0.69	0.79		
	RSD (%)	90	36	68	30	51	44		
C–I	Mean removal efficiency(%)	50	51	96	65	−126	8		
	SD of Removal efficiency (%)	25	13	4	12	87	33		
	n (number of events sampled)	7	4	4	4	4	4		

All weighted average concentrations (WAC) in mg L^{-1}. RSD = Relatives Standard Deviation; SD = Standard Deviation.
[a] Value omitted in calculations due to possible from glass sampling bottles.

in concentrations in Cr, Fe and Ni is due to leaching of clay minerals from the sand filter and the overlying topsoil. This leaching effect may explain that only certain trace elements exhibit an apparent increase in concentration in treated stormwater. However, Cr, Fe and Ni, and to a lesser extent Mn are not generally considered to be harmful to biota unless the concentrations exceed the water quality guideline prescribed by ANZECC (ANZECC, 1999). Although considerable work has been conducted on the increase in contaminants in remedial material used in infiltration beds with time (Lind and Karro,1995; Marsalek and Marsalek, 1997) and the quality of water being recharged from infiltration beds (Mikkelson *et al.*, 1994; Ellis, 2000), little data are readily available on the removal efficiency of these devices (Sansalone, 1999; Bardin *et al.*, 2001). Removal efficiencies for infiltration basins recommended for planning purposes by the Washington Council of Governments are TSS 75%, TP 60–70%, TN 55–60% and metals 85–90% (Schueler, 1987), which are very similar to the efficiencies determined in the current study.

The quality of water of the flowing in and out of the remedial device is compared to ANZECC water quality guidelines for freshwater (ANZECC, 1999) (Table IV and Figure 3). No guideline values are available for TSS, nutrients and FC, and enrichments are therefore not discussed for these parameters. The mean concentrations of trace metal analytes (Cr, Cu, Mn, Ni, Pb, Zn) in 46 samples obtained from the SIB inlet and 45 samples from the SIB outlet are used to determine the enrichment factor of the analyte before and after treatment by the device. No water,

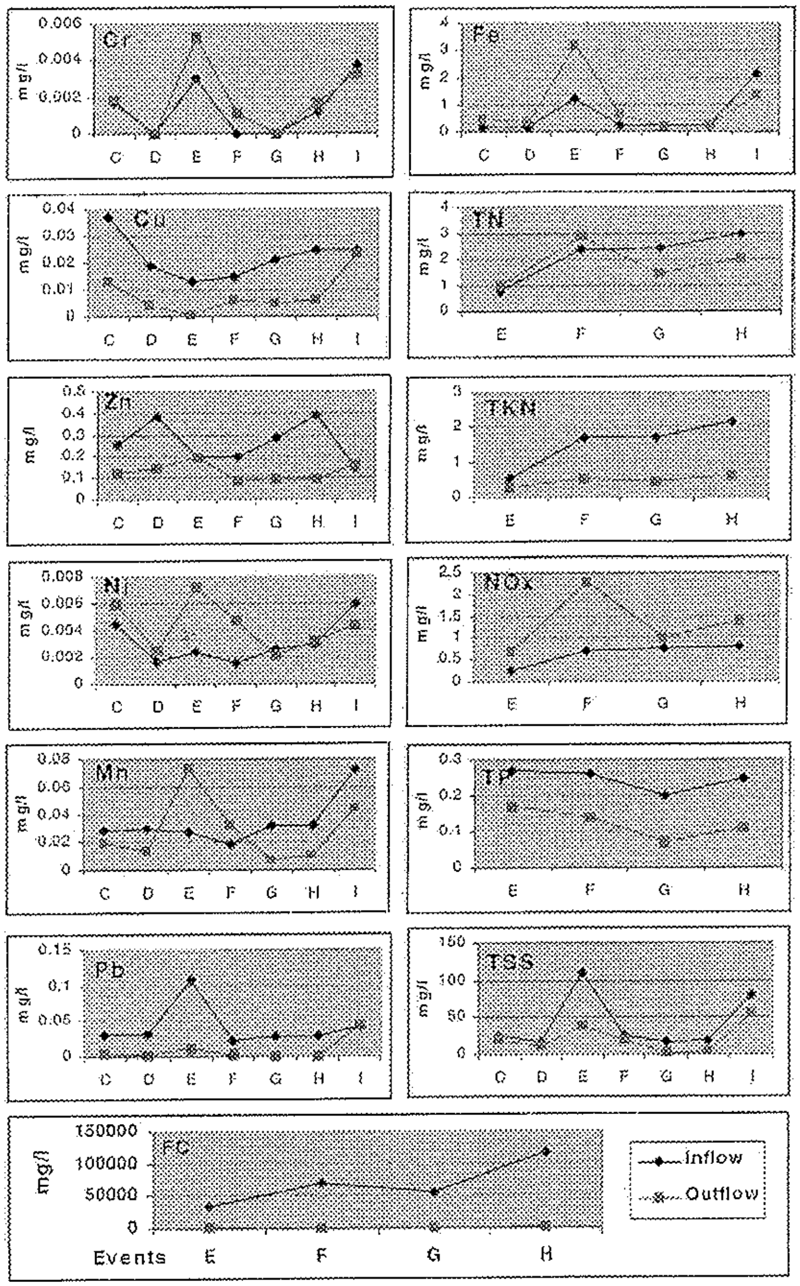

Figure 2. WAC of trace metals, nutrients, TSS and FC in stormwater runoff from inflow and outflow points at the SIB.

TABLE IV

Descriptive statistics and enrichment above water quality guidelines of trace metals, nutrients, faecal coliforms and TSS in stormwater samples from the catchment

		Cr	Cu	Fe	Pb	Mn	Ni	Zn	Tss	TP	FC	TKN	NOx	TN
Inlte	Maximum (mg/L)	0.01	0.078	7.7	0.360	0.290	0.017	0.850	504	0.49	300000	3.20	1.20	4.10
	Minimum (mg/L)	<0.001	0.007	0.03	<0.001	0.013	0.001	0.053	8	0.13	3000	0.31	0.03	0.47
	Mean (mg/L)	0.019	0.023	0.83	0.043	0.042	0.004	0.295	54	0.24	57031	1.70	0.81	2.51
	SD (mg/L)	0.0020	0.015	1.50	0.070	0.048	0.0030	0.152	96	0.10	71064	0.71	0.35	0.94
	RSD(%)	106	62	181	164	114	84	52	177	44	125	42	43	37
	n	46	46	46	46	46	46	46	46	26	26	26	26	26
	ANZECC (1999) (Freshwater) (mg/L)	0.0011	0.00033	−0.0012	0.047	0.0007	0.0024	nd	0.1[a]	1000[b]	0.032[c]	0.128	0.12[a]	0.1−0.5[d]
	Mean /ANZECC	1.7	71	–	35	0.9	5.1	123	nd	2.4	57	53	7	25
Outlet	Maximum (mg/L)	0.009	0.057	5.4	0.330	0.190	0.013	0.500	354	0.23	5700	0.94	2.6	3.20
	Minimum (mg/L)	<0.001	0.003	0.03	<0.001	0.003	0.001	0.056	1	0.025	290	0.36	0.78	1.19
	Mean (mg/L)	0.0023	0.011	1.00	0.020	0.036	0.005	0.161	40	0.11	2324	0.52	1.45	1.97
	SD (mg/L)	0.0020	0.010	1.30	0.056	0.040	0.0027	0.094	67	0.05	1649	0.1	0.6	0.7
	RSD (%)	90	96	130	275	112	58	58	169	44	71	24	40	33
	n	45	45	45	45	45	45	45	45	26	26	26	26	26
	ANZECC (1999) (Freshwater) (mg/L)	0.0011	0.00033	–	0.0012	0.047	0.0007	0.0024	nd	0.1[a]	1000[b]	0.032[c]	0.12[a]	0.1−0.5[d]
	Mean /ANZECC	2.1	33	–	17	0.8	6.6	67	nd	1.1	2.3	16	12	20

nd = no data; *n* = Number of samples; SD = Standard Deviation; RSD = Relative Standard Deviation.

[a] ANZECC (1999) trigger level for nitrate.

[b] Human health safety for secondary contact (LPRSWMP, 1999).

[c] ANZECC (1999) guidelines for ammonia.

[d] ANZECC (1992).

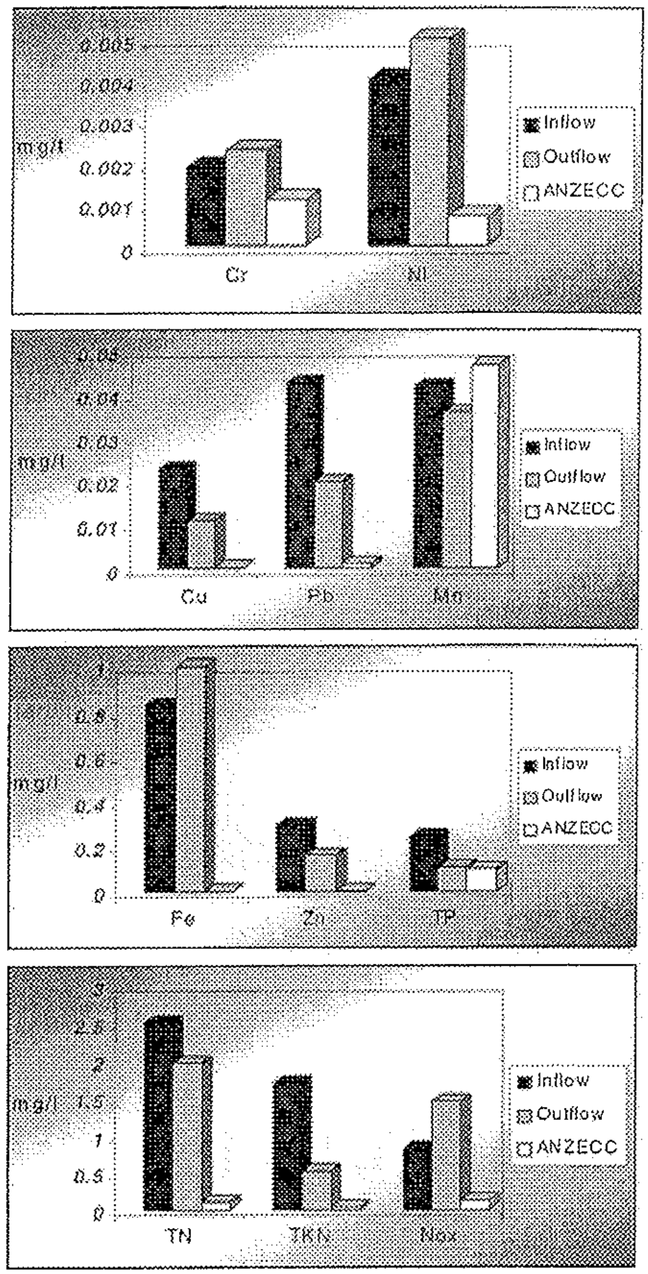

Figure 3. Comparative water quality guidelines of trace metsals and nutrients in stormwater runoff, from inlet and outlet of the SIB.

quality data are available, for Fe and Cd was below detection (<0.001 mg L^{-1}) in all samples. The mean concentrations of Mn in the inflowing and outflowing waters are 0.042 mg L^{-1} and 0.036 mg L^{-1}, respectively, which are below ANZECC water quality guideline for freshwater (0.047 mg L^{-1}). Mean concentrations of Cr exceed the ANZECC guideline value by 1.7 times and 2.1 times in the inflowing and outflowing waters, respectively. Similar to Cr, Ni displays a moderate enrichment above ANZECC guideline values of 5.1 and 6.6 times. In contrast, the enrichments of Cu, Pb and Zn in stormwater are substantially greater, ranging between 17 times and 123 times the recommended water quality guideline values. However, it should be noted that the mean concentrations of these metals in the outflowing waters are about 50% lower than in the inflowing waters (i.e., Cu decreases from 0.023 mg L^{-1} to 0.011 mg L^{-1}; Pb decreases from 0.043 mg L^{-1} to 0.020 mg L^{-1} and Zn decreases from 0.295 mg L^{-1} to 0.161 mg L^{-1}). The removal efficiency of trace metal contaminants by the SIB is therefore moderate to high, although the water quality of the stormwater remains above the ANZECC guidelines for freshwater following treatment by the SIB.

The mean concentrations of TKN, NO_x and TN in the inflowing stormwater are, respectively, 53 times, 7 times and 25 times greater than the ANZECC (1999) guideline values. Although the concentrations of TKN and TN in the outflowing waters of the SIB are substantially reduced, they remain 16 times and 20 times above the recommended ANZECC values, whereas concentrations of NO_x are 12 times the recommended concentration. The SIB is therefore not efficient at removing nitrate + nitrite from stormwater, but appears to support the oxidation of nitrogen due to an increased travel time during percolation of the stormwater through the sand filter. The longer travel time enables bacteria to oxidise organic nitrogen to ammonia and subsequently to nitrate, supporting the observed increase in the concentrations of NO_x in outflowing waters.

The mean concentration of TP decreases from 0.24 mg L^{-1} to 0.11 mg L^{-1}, effectively reducing the concentrations of phosphorus to concentrations recommended by the ANZECC (1992) guidelines.

The number of faecal coliform colonies per 100 mL of inflowing stormwater are very high, with a maximum of 300 000 cfu (100 mL)$^{-1}$ and a mean of 57 000 cfu (100 mL)$^{-1}$ ($n = 26$) recorded. The recommended number of FCs for human health safety for secondary contact (e.g., boating) are 1000 cfu (100 mL)$^{-1}$ (LPR-SWMP, 1999). In contrast, the mean FC content in outflowing stormwater from the SIB is ~2300 cfu (100 mL)$^{-1}$, which although still exceeding the recommended guideline value for human health safety for secondary contact, is a substantial improvement in stormwater quality (96%). The source of FC is unknown, although dog droppings are likely to contribute substantially to the stormwater in this catchment. Additional work is required to establish the source of the faecal bacteria, probably by quantifying the abundance of the human faecal indicator, *Clostridium Perfringens*.

TABLE V

Interelement correlations for trace metals (Cr, Cu, Fe, Mn, Ni, Pb, Zn) and TSS in 91 stormwater samples from the catchment

	Cr	Cu	Fe	Pb	Mn	Ni	Zn	TSS
Cr	1.00							
Cu	0.42	1.00						
Fe	0.92	0.29*	1.00					
Pb	0.58	0.65	0.43	1.00				
Mn	0.84	0.40	0.93	0.36	1.00			
Ni	0.80	0.32*	0.84	0.22**	0.85	1.00		
Zn	0.16***	0.65	0.08***	0.56	0.22**	0.07***	1.00	
TSS	0.82	0.61	0.75	0.87	0.71	0.56	0.44	1.00

$n = 91$ samples from seven events.
$P < 0.001$; $^{*}p < 0.01$; $^{**}p < 0.05$; $^{***}p > 0.05$.

The removal efficiency of organochlorine pesticides and PAHs could not be established from the data because concentrations of these contaminants in the stormwater were below detection for most analytes.

Although no work was conducted to quantify the partitioning of trace metals between dissolved and solid phases, it is likely that the majority of trace metals are associated with the suspended particulate matter in the stormwater. This assumption is supported by strong and significant correlations between trace metals and TSS in the stormwater runoff (R^2: 0.44–0.87; $p < 0.001$; $n = 91$) (Table V). Other strongly positive interelement correlations ($R^2 > 0.80$) in stormwater runoff at the SIB site include Fe:Cr, Cr:Mn, Cr:Ni, Fe:Mn, Fe:Ni and Mn:Ni (Table V).

4. Conclusions

The current study has shown that the SIB constructed in Eastern Sydney, is moderately to highly efficient in removing suspended particulate matter and the trace metals Cu, Pb and Zn from stormwater. FC contents in treated stormwater effluent are substantially reduced. In addition, concentrations of TP and TKN ($N_{org} + N_{am}$) are also moderately reduced by infiltration of stormwater through the SIB filter bed. However, the SIB was ineffective in reducing the concentrations of total nitrogen (TN) in treated effluent, although a conversion of TKN to NO_x was observed.

Concentrations of Cr, Fe and Ni were higher in stormwater effluent than influent possibly due to leaching of clay minerals from the SIB filter bed, however the concentrations of these elements are only moderately above recommended ANZECC guidelines for freshwater quality.

Acknowledgements

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Appendix 5

City of Verona Resolution No. 06-05-693 (with map)
Supporting Natural Resources Planning in Portions of
the Badger Mill Creek/Sugar River Watershed

CITY OF VERONA
RESOLUTION NO. 06-05-693

A RESOLUTION SUPPORTING NATURAL RESOURCES PLANNING IN PORTIONS OF THE BADGER MILL CREEK/SUGAR RIVER WATERSHED

WHEREAS, the City of Verona has a demonstrated history of promoting and practicing principles of sound planning and development throughout the City and is committed to continuing the practice; and

WHEREAS, the City recognizes the importance of environmental resources on the quality of life of our residents including the Badger Mill Creek and the Sugar River; and

WHEREAS, there are lands located as shown on the attached Exhibit A which may have future development potential in the City; and

WHEREAS, the impact from development of said lands on the Badger Mill Creek and Sugar River are not fully understood; and

WHEREAS, a comprehensive long-range planning process aimed at protecting the resources of the Badger Mill Creek and the Sugar River could assist the City in determining the development impact;

NOW, THEREFORE, BE IT RESOLVED by the Common Council of the City of Verona as follows:

1. That prior to permitting development of the area identified on the attached Exhibit A, the City of Verona will conduct a planning process designed to determine locations where development can occur in compliance with established federal, state, county and local rules and regulations.

2. That the City of Verona will include representatives from the Town of Verona, Dane County, the DNR, property owners and other stakeholders in the planning process; and

3. That the planning policies and concepts developed through the Badger Mill Creek and Sugar River natural resource planning process will be used to guide the development of the City's environmental protection and land use plans for the planning area.

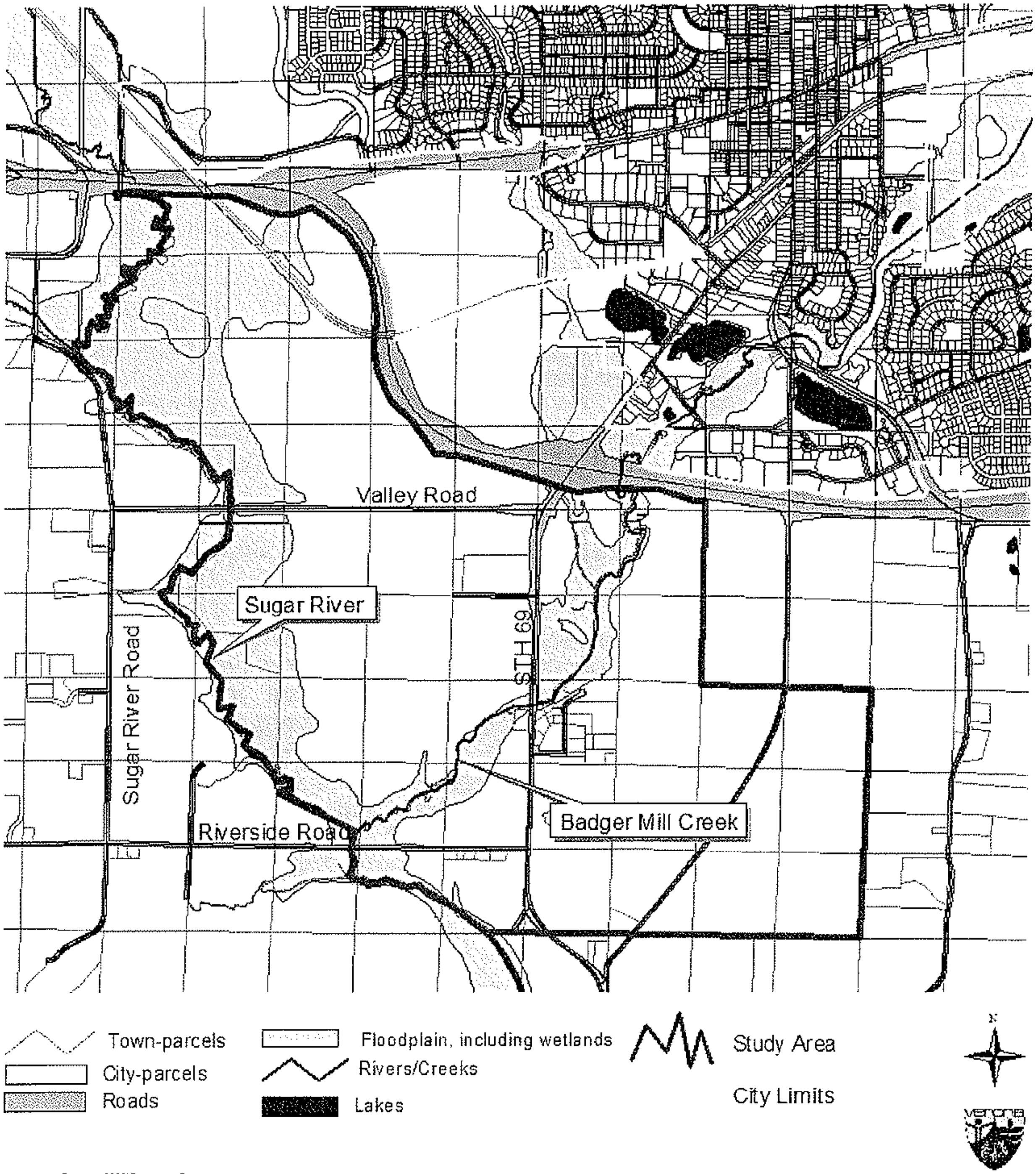
Signed and dated this 27th day of June, 2005.

CITY OF VERONA

By:
John B. Volker, Mayor

Attest:
JoAnn M. Wainwright, Clerk

Exhibit A



Valley Road
Sugar River
Sugar River Road
STH 69
Badger Mill Creek
Riverside Road
Town-parcels
City-parcels
Roads
Floodplain, including wetlands
Rivers/Creeks
Lakes
Study Area
City Limits
N